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BLAKISTON'S COMPENDS

A COMPEND OF HUMAN PHYSIOLOGY

ESPECIALLY ADAPTED FOR THE USE OF MEDICAL STUDENTS

BY

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FIFTEENTH EDITION

WITH 26 ILLUSTRATIONS

PHILADELPHIA
P. BLAKISTON'S SON & CO.
1012 WALNUT STREET

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A COMPEND

OF

HUMAN PHYSIOLOGY

Introduction.—An animal organism in the living condition exhibits a series of phenomena which relate to growth, movement, mentality, and reproduction. During the period preceding birth, as well as during the period included between birth and adult life, the individual grows in size and complexity from the introduction and assimilation of material from without. Throughout its life the animal exhibits a series of movements, in virtue of which it not only changes the relation of one part of its body to another, but also changes its position in space. If, in the execution of these movements, the parts are directed to the overcoming of opposing forces, such as gravity, friction, cohesion, elasticity, etc., the animal may be said to be doing work. The result of normal growth is the attainment of a physical development that will enable the animal, and, more especially, man, to perform the work necessitated by the nature of its environment and the character of its organization. In man, and probably in lower animals as well, mentality manifests itself as intellect, feeling, and volition. At a definite period in the life of the animal it reproduces itself, in consequence of which the species to which it belongs is perpetuated.

The study of the phenomena of growth, movement, mentality, and reproduction constitutes the science of ANIMAL PHYSIOLOGY. But as these general activities are the resultant of and dependent on the special activities of the individual structures of which an animal body is composed, Physiology in its more restricted and generally accepted sense is the science which investigates the actions or functions of the individual organs and tissues of the body and the physical and chemic conditions which underlie and determine them.

This may naturally be divided into:

1. *Individual physiology*, the object of which is a study of the vital phenomena or functions exhibited by the organs of any individual animal.

2. *Comparative physiology*, the object of which is a comparison of the vital phenomena or functions exhibited by the organs of two or more animals, with a view of unfolding their points of resemblance or dissimilarity.

Human physiology is that department of physiologic science which has for its object the study of the functions of the organs of the human body in a state of health.

If the body of any animal be dissected, it will be found to be composed of a number of well-defined structures, such as heart, lungs, stomach, brain, eye, etc., to which the term organ was originally applied, for the reason that they were supposed to be instruments capable of performing some important act or function in the general activities of the body. Though the term organ is usually employed to designate the larger and more familiar structures just mentioned, it is equally applicable to a large number of other structures which, though possibly less obvious, are equally important in maintaining the life of the individual—*e.g.*, bones, muscles, nerves, skin, teeth, glands, blood-vessels, etc. Indeed, any complexly organized structure capable of performing some function may be described as an organ. A description of the various organs which make up the body of an animal, their external form, their internal arrangement, their relations to one another, constitutes the science of ANIMAL ANATOMY.

This may naturally be divided into:

1. *Individual anatomy*, the object of which is the investigation of the construction, form, and arrangement of the organs of any individual animal.

2. *Comparative anatomy*, the object of which is a comparison of the organs of two or more animals, with a view of determining their points of resemblance or dissimilarity.

If the organs, however, are subjected to a further analysis, they can be resolved into simple structures, apparently homogeneous, to which the name tissue has been given—*e.g.*, epithelial, connective, muscle, and nerve tissue. When the tissues are subjected to microscopic analysis, it is found that they are not homogeneous in structure, but composed of still simpler elements, termed cells and fibers. The investigation of the internal structure of the organs, the physical properties and structure of the tissues, as well as the structure of their component elements, the cells and fibers, constitutes a department of anatomic science known as HISTOLOGY, or as it is prosecuted largely with the microscope, MICROSCOPIC ANATOMY.

Human anatomy is the department of anatomic science which has for its object the investigation of the construction of the human body.

Inasmuch as the study of function or physiology is associated with and dependent on a knowledge of structure, it is essential that the student should have a general acquaintance with the anatomy and histology not only of man but of typical forms of lower animal life as well. Moreover, since it has been demonstrated that every exhibition of functional activity is associated with changes in the composition of the structures, it has been apparent that a knowledge of the chemical composition of the body, as well as the successive changes in composition which it undergoes when in a state of functional activity, is necessary to a correct understanding of the intimate nature of physiologic processes.

Anatomic Systems.—All the organs of the body which have certain peculiarities of structure in common are classified by anatomists into systems—*e.g.*, the bones, collectively, constitute the bony or osseous system; the muscles, the nerves, the skin, constitute, respectively, the muscular, the nervous, and the tegumentary system.

Physiologic Apparatus.—More important from a physiologic point of view than a classification of organs based on similarities of structure is the natural association of two or more organs acting together for the accomplishment of some definite object, and to which the term physiologic apparatus has been applied. While in the community of organs which together constitute the animal body each one performs some definite function, and the harmonious coöperation of all is necessary to the life of the individual, everywhere it is found that two or more organs, though performing totally distinct functions, are coöperating for the accomplishment of some larger or compound function in which their individual functions are blended—*e.g.*, the mouth, stomach, and intestines, with the glands connected with them, constitute the *digestive apparatus*, the object or function of which is the complete digestion of the food. The capillary blood-vessels and lymphatic vessels of the body, and especially those in relation to the villi of the small intestine, constitute the *absorptive apparatus*, the function of which is the introduction of new material into the blood. The heart and blood-vessels constitute the *circulatory apparatus*, the function of which is the distribution of blood to all portions of the body. The lungs and trachea, together with the diaphragm and the walls of the chest, constitute the *respiratory apparatus*, the function of which is the introduction of oxygen into the blood and the elimination from it of carbon dioxid and other injurious products. The kidneys, the ureters, and the bladder constitute the *urinary apparatus*. The skin, with its sweat-glands, constitutes the *perspiratory apparatus*, the functions of both being the excretion of waste products from the body. The liver, the pancreas the mammary glands, as well as other glands, each form a *secretory apparatus* which elaborates some specific material necessary to the nutrition of the individual. The functions of these different physiologic apparatus —*e.g.*, digestion, absorption of food, elaboration of blood, circulation of blood, respiration, production of heat, secretion and excretion—are classified as *nutritive functions*, and have for their final object the preservation of the individual.

The nerves and muscles constitute the *nervo-muscular apparatus*, the function of which is the production of motion. The eye, the ear, the nose, the tongue, and the skin, with their related structures, constitute, respectively, the *visual*, *auditory*, *olfactory*, *gustatory*, and *tactile apparatus*, the function of which, as a whole, is the reception of impressions and the transmission of nerve impulses to the brain, where they give rise to visual, auditory, olfactory, gustatory, and tactile sensations.

The brain, in association with the sense organs, forms an apparatus related to mental processes. The larynx and its accessory organs—the lungs, trachea, respiratory muscles, the mouth and resonant cavities of the face—form the *vocal* and *articulating apparatus*, by means of which voice and articulate speech are produced. The functions exhibited by the apparatus just mentioned—viz., motion, sensation, language, mental and moral manifestations—are classified as *functions of relation*, as they serve to bring the individual into conscious relationship with the external world.

The ovaries and the testes are the essential reproductive organs, the former producing the germ-cell, the latter the spermatic element; together with their related structures—the fallopian tubes, uterus, and vagina in the female, and the urogenital canal in the male—they constitute the *reproductive apparatus* characteristic of the two sexes. Their coöperation results in the union of the germ-cell and spermatic element and the consequent development of a new being. The function of reproduction serves to perpetuate the species to which the individual belongs.

The animal body is therefore not a homogeneous organism, but one composed of a large number of widely dissimilar but related organs. But as all vertebrate animals have the same general plan of organization, there is a marked similarity both in form and structure among corresponding parts of different animals. Hence it is that in the study of human anatomy a knowledge of the form, construction, and arrangement of the organs in different types of animal life is essential to its correct interpretation; also it is that in the investigation and comprehension of the complex problems of human physiology a knowledge of the *functions* of the organs as they manifest themselves in the different types of animal life is indispensable. As many of the functions of the human body are not only complex, but the organs exhibiting them are practically inaccessible to investigation, we must supplement our knowledge and judge of their functions by analogy, by attributing to them, within certain limits, the functions revealed by experimentation upon the corresponding but simpler organs of lower animals. This experimental knowledge corrected by a study of the clinical phenomena of disease and the results of post-mortem investigations, forms the basis of modern human physiology.

PHYSIOLOGY OF THE CELL

A histologic analysis of the tissues shows that they can be resolved into simpler elements, termed cells, which may, therefore, be regarded as the primary units of structure. Though cells vary considerably in shape, size and chemic composition in the different tissues of the adult body, they are nevertheless, descendants from typical cells, known as embryonic or undifferentiated cells, the first offspring of the fertilized ovum. Ascending the line of embryonic development, it will be found that every organized body originates in a single cell—the ovum. As the cell is the elementary unit of all tissues, the function of each tissue must be referred to the function of the cell. Hence the cell may be defined as the primary anatomic and physiologic unit of the organic world, to which every exhibition of life, whether normal or abnormal is to be referred.

Structure of Cells.—Though cells vary in shape and size and internal structure in different portions of the body, a typical cell may be said to consist mainly of a gelatinous substance forming the body of the cell, termed *cytoplasm* or *bioplasm,* in which is embedded a smaller spheric body, the *nucleus.* Within the nucleus there is frequently a still smaller body the nucleolus. The shape of the adult cell varies according to the tissue in which it is found; when young and free to move in a fluid medium, the cell assumes a spheric form, but when subjected to pressure, may become cylindric, fusiform, polygonal, or stellate. Cells vary in size within wide limits, ranging from $\frac{1}{3200}$ of an inch, the diameter of a red blood-corpuscle to $\frac{1}{200}$ of an inch, the diameter of the large cells in the gray matter of the spinal cord.

The **cell cytoplasm** consists of a soft, semifluid, gelatinous material, varying somewhat in appearance in different tissues. Though frequently homogeneous, it often exhibits a finely granular appearance under medium powers of the microscope. Young cells consists almost entirely of clear cytoplasm, mature cells contain, according to the tissue in which they are found, material of an entirely different character—*e.g.*, small globules of fat, granules of glycogen, mucigen, pigments, digestive ferments, etc. Under high powers of the microscope the cytoplasm is found to be pervaded by a network of fibers, termed *spongioplasm*, in the meshes of which is contained a clearer and more fluent substance, the *hyaloplasm*. The relative amount of these two constituents varies in different cells, the proportion of hyaloplasm being usually greater in young cells. The arrangement of the fibers forming the spongioplasm also varies, the fibers having sometimes a radial direction, in others a concentric disposition, but most frequently being distributed evenly in all directions. In many cells the outer portion of the cell cytoplasm undergoes chemic changes and is transformed into a thin, transparent, homogenous membrane—the *cell membrane*—which completely incloses the cell substance. The cell membrane is permeable to water and watery solutions of various inorganic and organic substances. It is, however, not an essential part of the cell.

The **nucleus** is a small vesicular body embedded in the cytoplasm near the center of the cell. In the resting condition of the cell it consists of a distinct membrane, composed of *amphipyrenin*, inclosing the nuclear contents. The latter consists of a homogenous amorphous substance—the nuclear matrix—in which is embedded the nuclear network. It can often be seen that a portion of one side of the nucleus, called the pole, is free from this network. The main cords of the network are arranged as V-shaped loops about it. These main cords send out secondary branches or twigs, which, uniting with one another, complete the network. The nuclear cords are composed of granules of *chromatin*—so called because of its affinity for certain staining materials—held together by an achromatin substance known as *linen*. Besides the nuclear network, there are embedded in the nuclear matrix one or more small bodies composed of *pyrenin* known as *nucleoli*. At the pole of the nucleus, either within or just without in the cytoplasm, is a small body, the *centrosome*, or pole corpuscle.

Chemic Composition of the Cell.—The composition of living protoplasm is difficult of determination, for the reason that all chemic and physical methods employed for its analysis destroy its vitality, and the products obtained are peculiar to dead rather than to living matter. Moreover, as protoplasm is the seat of constructive and destructive processes, it is not easy to determine whether the products of analysis are crude food constituents or cleavage or disintegration products. Nevertheless, chemic investigations have shown that even in the living condition protoplasm is a highly complex compound—the resultant of the intimate union of many different substances. About seventy-five per cent. of protoplasm consists of water and twenty-five per cent. of solids, of which the more important compounds are various nucleo-proteins (characterized by their large percentage of phosphorus), globulins, traces of lecithin, cholesterin and frequently fat and carbohydrates. Inorganic salts, especially the potassium, sodium, and calcium chlorids and phosphates, are almost invariable and essential constituents.

MANIFESTATIONS OF CELL LIFE

Growth, the Maintenance of Nutrition, and Reproduction.—All cells exhibit three fundamental properties of life—viz., growth, the maintenance of their nutrition, and reproduction. Growth is an increase in size. When newly reproduced all cells are extremely small, but in consequence of their organization and the character of their surrounding medium, they gradually grow until they attain the size characteristic of the adult state.

Nutrition may be defined as the sum of the processes concerned in the maintenance of the physiologic condition of the cell and includes both growth and repair. So long as this is accomplished, the cells and the tissues which are formed by them continue to exhibit their functions or their characteristic modes of activity. Both growth and nutrition are dependent on the power which living material possesses of not only absorbing nutritive material from the surrounding medium, the lymph, but of subsequently assimilating it, organizing it, transforming it into material like itself and endowing it with its own physiologic properties.

In the physiologic condition the living material of the cell, the bioplasm, is the seat of a series of chemic changes which vary in degree from moment to moment in accordance with the degree of functional activity, and on the continuance of which all life phenomena depend. Some of these chemic changes are related to or connected with the molecules of the living material, while othess are connected with the food material supplied to them. Of the chemic changes occurring within the molecules some are destructive, dissimilative or disintegrative in character, whereby the molecule is in part eventually reduced through a series of descending chemic stages to simpler compounds which, apparently of no use in the cell, are eliminated from it. It is, therefore, said that the living material undergoes molecular disintegration as a result of functional activity. To these changes the term *katabolism* is also applied. Other of these changes are constructive, assimilative or integrative in character, whereby a part at least of the food material furnished by the blood-plasma is transformed through a series of ascending chemic stages into living material, and whereby it is repaired and its former physiologic condition restored. It is, therefore, said that the living material undergoes molecular integration as a preparation for functional activity. To these changes the term *anabolism* is also applied. During the course of its physiologic activities the cell bioplasm produces materials of an entirely different character which vary with the cell, such as fat, glycogen, mucigen, pigments, ferments, etc., which are generally spoken of as metabolic products.

Living material has also a temperature varying in degree in different species of animals as well as in different parts of the same animal. Here as elsewhere the temperature is due to heat liberated from organic compounds through disruption and subsequent oxidation to simpler compounds. Though some of the heat liberated may come from the tissue molecules, the larger part by far comes from the food molecules—sugar, fat, and protein, constituents of the fluids circulating in the tissue spaces. These foods carry into the body potential energy, ultimately derived from the sun. Whey they are disrupted and oxidized the potential energy is transformed into kinetic energy which manifests itself for the most part as heat. To the sum total of all the chemic changes occurring in tissues and foods the term *metabolism* is given.

Physiologic Properties of Protoplasm.—All living protoplasm possesses properties which serve to distinguish and characterize it—viz., irritability, conductivity, and motility.

Irritability, or the power of reacting in a definite manner to some form of external excitation, whether mechanical, chemic, or electric, is a fundamental property of all living protoplasm. The character and extent of the reaction will vary, and will depend both on the nature of the protoplasm and the character and strength of the stimulus. If the protoplasm be muscle, the response will be a contraction; if it be gland, the response will be secretion; if it be nerve, the response will be a sensation or some other form of nerve activity.

Conductivity, or the power of transmitting moleculat disturbances arising at one point to all portions of the irritable material, is also a characteristic feature of all protoplasm. This power, however, is best developed in that form of protoplasm found in nerves, which serves to transmit, with extreme rapidity, molecular disturbances arising at the periphery to the brain, as well as in the reverse direction. Muscle protoplasm also possesses the same power in a high degree.

Motility, or the power of executing apparently spontaneous movements, is exhibited by many forms of cell protoplasm. In addition to the molecular movements which take place in certain cells, other forms of movement are exhibited, more or less constantly, by many cells in the animal body—*e.g.*, the waving of cilia, the ameboid movements and migrations of white blood corpuscles, the activities of spermatozooids, the projections of pseudopodia, etc. These movements, arising without any recognizable cause, are frequently spoken of as spontaneous. Strictly speaking, however, all protoplasmic movement is the resultant of natural causes, the true nature of which is beyond the reach of present methods of investigation.

Reproduction.—Cells reproduce themselves in the higher animals in two ways—by direct division and by indirect division, or karyokinesis. In the former the nucleus becomes constricted, and divides without any special grouping of the nuclear elements. It is probable that this occurs only in disintegrating cells, and never in a physiologic multiplication. In division by karyokinesis there is a progressive rearranging and definite grouping of the nucleus, the result of which changes is the division of the centrosome, the chromatin, and the rest of the nucleus into two equal portions, which form the nuclei. Following the division of the nuclei, the protoplasm becomes constricted midway between the young nuclei. This constriction gradually deepens until the original cell is divided, with the formation of two complete cells.

THE PHYSIOLOGY OF THE SKELETON

The animal body is characterized by the power of executing a great variety of movements, all of which have reference to a change of relation of one part of the body to another, or to a change of position of the individual in its environment, as in the various acts of locomotion. If in the execution of these movements the different parts are applied or directed to the overcoming of opposing forces in the environment, the animal is said to be doing work. In the conception of the animal body as a machine for the accomplishment of work the skeleton, the muscle and nerve tissues, constitute the three primary mechanisms, all of which bear certain definite relations one to another.

The skeleton in its entirety determines the plan of organization of the animal body and imparts to it its characteristic features. In its entirety it serves for the attachment of muscles, the support of viscera and by reason of the relation of the bones one to another, permits of a great variety of movements. The skeleton may be divided into an axial and an appendicular portion.

The Axial Portion.—The axial portion consists of the bones of the head, of the vertebral column and the ribs. The vertebral column is the foundation element and the center around which the appendicular portions are developed and arranged with a certain degree of conformity. It is composed of a series of superimposed bones, termed vertebræ, which increase in size from above downward as far as the brim of the pelvic cavity. Superiorly, it supports the skull; laterally, it affords attachment for the ribs, which in turn support the weight of the upper extremities; below, it rests upon the pelvic bones, which transmit the weight of the body to the inferior extremities. The bodies of the vertebræ are united one to another by tough elastic discs of fibro-cartilage, which, collectively, constitute about one-quarter of the length of the vertebral column. The vertebræ are held together by ligaments situated on the anterior and posterior surfaces of their bodies, and by short, elastic ligaments between the neural arches and processes. These structures combine to render the vertebral column elastic and flexible, and enable it to resist and diminish the force of shocks communicated to it. The character and the arrangement of the bones of the axial portion endow the animal mechanism with a certain degree of fixity combined with slight mobility.

The Appendicular Portion.—The appendicular portion consists of the bones of the arms and legs, the scapular and pelvic arches. By reason of its character and anatomic arrangement, the animal body is endowed with extreme mobility, enabling the animal to execute a great variety of rapid and extensive movements which, however, vary in degree in different animals in accordance with their organization and the nature of their environment.

For the manifestation of the activities of the animal it is essential that the relation of the various portions of the bony skeleton to one another shall be such as to permit of movement while yet retaining close apposition. This is accomplished by the mechanical conditions which have been evolved at the points of union of bones, and which are technically known as articulations or joints.

A consideration of the body movements involves an account of (1) the static conditions, or those states of equilibrium in which the body is at rest—*e.g.*, standing, sitting; (2) the dynamic conditions or those states of activity characterized by movement—*e.g.*, walking, running, etc. In this connection, however, only those physical and physiologic peculiarities of the skeleton, especially in its relation to joints, will be referred to which underlie and determine both the static and dynamic states of the body.

Structure of Joints.—The structures entering into the formation of joints are:

1. *Bones*, the articulating surfaces of which are often more or less expanded, especially in the case of long bones, and at the same time variously modified and adapted to one another in accordance with the character and extent of the movements which there take place.

2. *Hyaline cartilage*, which is closely applied to the articulating end of each bone. The smoothness of this form of cartilage facilitates the movements of the opposing surfaces, while its elasticity diminishes the force of shocks and jars imparted to the bones during various muscular acts. In a number of joints, plates or discs of white fibro-cartilage are inserted between the surfaces of the bones.

3. *A synovial membrane*, which is attached to the edge of the hyaline cartilage entirely inclosing the cavity of the joint. This membrane is composed largely of connective tissue, the inner surface of which is lined by endothelial cells, which secrete a clear, colorless, viscid fluid—the synovia. This fluid not only fills up the joint-cavity, but, flowing over the articulating surfaces, diminishes or prevents friction.

4. *Ligaments*—tough, inelastic bands, composed of white fibrous tissue—which pass from bone to bone in various directions on the different aspects of the joint. As white fibrous tissue is inextensible but pliant, ligaments assist in keeping the bones in apposition, and prevent displacement while yet permitting of free and easy movements.

Classification of Joints.—All joints may be divided, according to the extent and kind of movements permitted by them, into (1) diarthroses; (2) amphiarthroses; (3) synarthroses.

A. Diarthroses.—In this division of the joints are included all those which permit of free movement. In the majority of instances the articulating surfaces are mutually adapted to each other. If the articulating surface of one bone is convex, the opposing but corresponding surface is concave. Each surface, therefore, represents a section of a sphere or cylinder, which latter arises by rotation of a line around an axis in space. According to the number of axes around which the movements take place all diarthrodial joints may be divided into:

1. Uniaxial Joints.—In this group the convex articulating surface is a segment of a cylinder or cone, to which the opposing surface more or less

completely corresponds. In such a joint the single axis of rotation, though, practically is not exactly at right angles to the long axis of the bone, and hence the movements—flexion and extension—which take place are not confined to one plane. Joints of this character—*e.g.*, the elbow, knee, ankle, the phalangeal joints of the fingers and toes—are, therefore, termed ginglymi, or hinge-joints. Owing to the obliquity of their articulating surfaces, the elbow and ankle are *cochleoid* or *screw-ginglymi.* Inasmuch as the axes of these joints on the opposite sides of the body are not coincident, the right elbow and left ankle are right-handed screws; the left elbow and right ankle, left-handed screws. In the knee-joint the form and arrangement of the articulating surfaces are such as to produce that modification of a simple hinge known as a *spiral hinge*, or *helicoid.* As the articulating surfaces of the condyles of the femur increase in convexity from before backward, and as the inner condyle is longer than the outer, and therefore, represents a spiral surface, the line of translation or the movement of the leg is also a spiral movement. During flexion of the leg there is a simultaneous inward rotation around a vertical axis passing through the outer condyle of the femur; during extension a reverse movement takes place. Moreover, the slightly concave articulating surfaces of the tibia do not revolve around a single fixed transverse axis, as in the elbow-joint, for during flexion they slide backward, during extension forward, around a shifting axis, which varies in position with the point of contact.

In some few instances the long axis of the articulating surface is parallel rather than transverse to the long axis, and as the movement then takes place around a more or less conic surface, the joint is termed a *trochoid* or pulley—*e.g.*, the odonto-atlantal and the radio-ulnar. In the former the collar formed by the atlas and its transverse ligaments rotates around the vertical odontoid process of the axis. In the latter the head of the radius revolves around its own long axis upon the ulna, giving rise to the movements of pronation and supination of the hand. The axis around which these two movements take place is continued through the head of the radius of the styloid process of the ulna.

2. Biaxial Joints.—In this group the articulating surfaces are unequally curved, though intersecting each other. When the surfaces lie in the same direction, the joint is termed an *ovoid* joint—*e.g.*, the radio-carpal and the atlanto-occipital. As the axes of these surfaces are vertical to each other, the movements permitted by the former joint are flexion, extension, adduction, and abduction, combined with a slight amount of circumduction; the latter joint permits of flexion and extension of the

head, with inclination to either side. When the surfaces do not take the same direction, the joint, from its resemblance to the surfaces of a saddle, is termed a saddle-joint—*e.g.*, the trapezio-metacarpal. The movements permitted by this joint are also flexion, extension, adduction, abduction, and circumduction.

3. Polyaxial Joints.—In this group the convex articulating surface is a segment of a sphere, which is received by a socket formed by the opposing articulating surface. In such a joint, termed an *enarthrodial* or ball-and-socket joint—*e.g.*, the shoulder-joint, hip-joint—the distal bone revolves around an indefinite number of axes, all of which intersect one another at the center of rotation. For simplicity, however, the movement may be described as taking place around axes in the three ordinal planes—viz., a transverse, a sagittal, and a vertical axis. The movements around the transverse axis are termed flexion and extension; around the sagittal axis, adduction and abduction; around the vertical axis, rotation. When the bone revolves around the surface of an imaginary cone, the apex of which is the center of rotation and the base the curve described by the hand, the movement is termed circumduction.

B. Amphiarthroses.—In this division are included all these joints which permit of but slight movement—*e.g.*, the intervertebral, the interpubic, and the sacro-iliac joints. The surfaces of the opposing bones are united and held in position largely by the intervention of a firm, elastic disc of fibro-cartilage. Each joint is also strengthened by ligaments.

C. Synarthroses.—In this division are included all those joints in which the opposing surfaces of the bones are immovably united, and hence do not permit of any movement—*e.g.*, the joints between the bones of the skull.

Levers.—In the animal machine, as in physical machines generally, work is accomplished by the intermediation of levers. The bones collectively constitute a system of levers the fulcra of which lie in the joints. The long bones more especially, are the levers which are employed by the muscles to overcome the opposing forces or resistances. The structure and the chemic composition of the bones, consisting as they do of inorganic matter 67 per cent. and of organic matter 33 per cent. endow them with both rigidity and elasticity, physical properties which admirably adapt them to the character of the work necessitated by the environment and the organization of the animal.

That a lever may be effective as an instrument for the accomplishment of work, it must not only be capable of moving around its fulcrum, but it must at the same time be acted on by two opposing forces, one passive, the other active. In the movement of the bony levers of the animal body, the *passive* forces are largely those connected with the environment, *e.g.*, gravity, cohesion, friction, elasticity, etc. The *active* forces by which these latter are opposed and overcome through the intermediation of the bony levers are found in the muscles attached to them.

In all the static and dynamic states of the body the vertebral column plays a most essential rôle. The amphiarthrodial character of the intervertebral joint endows the entire column with certain forms of movement that are necessary to the performance of many body activities.

While the range of movement between any two vertebræ is slight, the sum total of movement of the entire series of vertebræ is considerable. In different regions of the column the character, as well as the range of movement, varies in accordance with the forms of the vertebræ and the inclination of their articular processes. In the cervical and lumbar regions extension and flexion are freely permitted, though the former is greater in the cervical, the latter in the lumbar region, especially between the fourth and fifth vertebræ. Lateral flexion takes place in all portions of the column, but is particularly marked in the cervical region. A rotatory movement of the column as a whole takes place through an angle of about twenty-eight degrees. This is most evident in the lower cervical and dorsal regions.

The diarthrodial character of the joints of the appendicular portions permit of extremely free movements. The character of the movements as well as their extent depends largely on the shape and adjustment of the bones at their points of union.

GENERAL PHYSIOLOGY OF MUSCLE TISSUE

The **muscle tissue,** which closely invests the bones of the body, and which is familiar to all as the flesh of animals, is the immediate cause of the active movements of the body. This tissue is grouped in masses of varying size and shape, which are technically known as muscles. The majority of the muscles of the body are connected with the bones of the skeleton in such a manner that, by an alteration in their form, they can change not only the position of the bones with reference to one another, but can also change the individual's relation to surrounding objects. They are, therefore, the active organs of both motion and locomotion, in contradistinction to the bones and joints, which are but passive agents in the performance of the corresponding movements. In addition to the muscle masses which are attached to the skeleton, there are also other collections of muscle tissue surrounding cavities such as the stomach, intestine, blood-vessels, etc., which impart to their walls motility, and so influence the passage of a material through them.

Muscles produce movement of the structures to which they are attached by the property with which they are endowed of changing their shape, shortening or *contracting* under the influence of a stimulus transmitted to them from the nervous system. Muscles are therefore divided into:

1. *Skeletal* muscles, comprising those muscles which are attached to the various bones of the skeleton.

2. *Visceral* muscles, comprising those muscles which are found in and which compose a portion of the walls of the hollow viscera.

As the skeletal muscles are capable of being excited to activity by nerve impulses descending from the cerebrum as a result of volition they are frequently termed voluntary muscles. By reason of their appearance as seen under the microscope they are termed also striped or striated muscles. As the visceral muscles are not capable of being excited to action by volition they are frequently termed involuntary muscles. By reason of their appearance as seen under the microscope they are termed also non-striated or smooth muscles.

Though for the most part the skeletal muscles are *red* in color, there are certain muscles in man and other animals which are *pale* in color and in many muscles, pale fibers are extensively distributed among the red fibers.

The Skeletal Muscle.—All skeletal muscles consist of a central fleshy portion, the body or belly, which is provided at either extremity with a tendon in the form of a cord or membrane by which it is attached to the bones. The body is the contractile region, the source of activity; the tendon is a passive region, and merely transmits the activity to the bones.

A skeletal muscle is a complex organ consisting of muscular fibers, connective tissue, blood-vessels, and lymphatics. The general body of the muscle is surrounded by a dense layer of connective-tissue, the *epimysium*, which blends with and partly forms the tendon; from its inner surface septa of connective tissue pass inward and group the muscle-fibers into larger and smaller bundles, termed *fasciculi*. The fasciculi, invested by this special sheath, the *perimysium*, are irregular in shape, and vary considerably in size. The fibers of the fasciculi are separated from one another and supported by a delicate connective tissue, the *endomysium*. The connective tissue thus surrounding and penetrating the muscle binds its fibers into a distinct organ, and affords support to blood-vessels, nerve, and lymphatics. The muscle fibers are arranged parallel to one another, and their direction is that of the long axis of the muscle. In length they vary from thirty to forty millimeters, and in diameter from twenty to thirty micromillimeters.

Histology of the Skeletal Muscle-Fiber.—A muscle-fiber consists of a transparent elastic membrane, the *sarcolemma,* in which is contained the true muscle element. Examined microscopically, the fiber presents a series of alternate dim and bright bands, giving to it a striated appearance.

When the bright band is examined with high magnifying powers, a fine, dark line is seen crossing it transversely. It was supposed by Krause to be the optic expression of a membrane attached laterally to the sarcolemma.

The muscle-fiber also exhibits a longitudinal striation, indicating that it is composed of fibrillæ, placed side by side and embedded in some interfibrillar substance, to which the name *sarcoplasm* has been given. The fibrillæ, which are arranged longitudinally to the long axis of the fiber, are grouped by the intervening material into bundles of varying size, the *muscle columns.* The fibrillæ which extend throughout the length of the fiber are apparently of uniform thickness, passing directly through the transverse membrane and being supported by it.

In the region of the dim band the fibrilla presents itself in the form of a homogeneous prismatic rod, termed *sarcostyle,* separated from neighboring rods by a slight amount of sacroplasm.

The Blood Supply.—The blood supply to the muscle is very great, and the disposition of the capillary vessels, with reference to muscle-fiber, is very characteristic. The arterial vessels, after entering the muscle, are supported by the perimysium; in this situation they give off short, transverse branches, which immediately break up into a capillary network of rectangular shape, within which the muscle-fibers are contained. The muscle-fiber in intimate relation with the capillary is bathed with lymph derived from it. Its contractile substance, however, is separated from the lymph by its own investing membrane, through which all interchange of nutritive and waste materials must take place. Lymphatics are present in muscle, but are confined to the connective tissue, in the spaces of which they have their origin.

The Nerve Supply.—The nerves which carry the stimuli to a muscle enter near its geometric center. Many of the fibers pass directly to the muscle-fibers with which they are connected; others are distributed to blood-vessels. Every muscle-fiber is supplied with a special nerve-fiber, except in those instances where the nerve trunks entering a muscle do not contain so many fibers as the muscle. In such cases the nerve-fibers divide, until the number of branches equals the number of muscle-fibers.

The individual muscle-fiber is penetrated near its center by the nerve, the ends being practically free from nerve influence. The stimulus that comes to the muscle fiber acts primarily upon its center, and then travels in both directions to the ends.

Chemic Composition of Muscle.—The chemic composition of muscle, is imperfectly understood, owing to the fact that some of its constituents undergo a spontaneous coagulation after death, and that the chemic methods employed also tend to alter its normal composition. When fresh muscle is freed from fat and connective tissue, frozen, rubbed up in a mortar, and expressed through linen, a slightly yellow, syrupy, alkaline, or neutral fluid is obtained, known as *muscle plasma*. This fluid at normal temperature coagulates spontaneously, and resembles in many respects the coagulation of blood plasma. The coagulum subsequently contracts and squeezes out an acid *muscle serum*. The coagulated mass is termed *myosin* or *myogen fibrin*. This protein belongs to the class of globulins. Inasmuch as it is not present in living muscle, and makes its appearance only in the as yet living muscle plasma, it is probable that it is derived from some preexisting substance, which is supposed to be *myosinogen* or *myogen*. Myosin is digested by pepsin and trypsin. According to Halliburton, muscle plasma contains the following protein bodies: Myosinogen, paramyosinogen, albumin, myoalbumose, all of which differ in chemic composition and respond to various chemic and physical reagents.

Ferment bodies, such as pepsin and diastase; non-nitrogenized bodies, such as glycogen, lactic and sarcolactic acids, fatty bodies, and inosite; nitrogenized extractives—*e.g.*, urea, uric acid, kreatinin, as well as inorganic salts, have been obtained from the muscle serum.

The Physical Properties of Muscle Tissue.—The *consistency* of muscle tissue varies considerably, according to the different states of the muscle. In a state of tension it is hard and resistant; when free from tension, it is soft and fluctuating, whether the muscle is contracting or resting. Tension alone produces hardness. The *cohesion* of muscle tissue is less than that of connective tissue, and is broken more readily. Cohesion resists traction and pressure, and lasts as long as irritability remains.

The *elasticity* of a muscle, though not great, is almost perfect. After being extended by a weight, it returns to its natural form. The limit of elasticity, however, is soon passed. A weight of 50 or 100 grams will overcome the elasticity so that it will not return to its natural length. In inorganic bodies the extension is directly proportional to the extending weight, and the line of extension is straight. With muscles, the extension is not proportional to the weight. While at first it is marked, the elongation diminishes as the weight increases by equal increments, so that the line of extension becomes a curve. In other words, the elasticity of a passive muscle augments with increased extension. On the contrary the elasticity of an active is less than that of a passive muscle, for it is elongated more by the same weight, as shown by experiment.

Tonicity is a property of all muscles in the body, in consequence of being normally stretched to a slight extent beyond their natural length. This may be due to the action of antagonistic muscles, or to the elasticity of the parts of the skeleton to which they are attached. This is shown by the shortening of the muscle which takes place when it is divided. Muscular tonus plays an important rôle in muscular contraction. Being always on the stretch, the muscle loses no time in acquiring that degree of tension necessary to its immediate action on the bones. Again, the working power of a muscle is increased by the presence of some resistance to the act of contraction. According to Marey, the amount of work is considerably increased when the muscular energy is transmitted by an elastic body to the mass to be moved, while at the same time, the shock of the contraction is lessened. The position of a passive limb is the resultant also of the elastic tension of antagonistic groups of muscles.

Muscle excitability and **contractility** are terms employed to denote that property of muscle tissue in virtue of which it contracts or shortens in response to various excitants or stimuli. Though usually associated with the activity of the nervous system, it is nevertheless an independent endowment, and persists after all nervous connections are destroyed. If the nerve terminals be destroyed, as they can be by the introduction of curara into the system, the muscles become completely relaxed and quiescent. The strongest stimuli applied to the nerves fail to produce a contraction. Various external stimuli applied directly to the muscle substance produce at once the characteristic contraction. The excitability of muscle is therefore an inherent property, dependent on its nutrition, and persisting as long as it is supplied with proper nutritive materials and surrounded by those external conditions which maintain its chemic or physical integrity.

Muscle Contractions.—All muscle contractions occurring in the body under normal physiologic conditions are either *voluntary*, caused by a volitional effort and the transmission of a nerve impulse from the brain through the spinal cord and nerves to the muscles, or *reflex*, caused by a peripheral stimulation and the transmission of a nerve impulse to the spinal cord, to be reflected outward through the same nerves to the muscles. In either case the resulting contraction is essentially the same. The *normal* or *physiologic stimulus* which provokes the muscular contraction is a nerve impulse the nature of which is unknown, but is perhaps allied to a molecular disturbance. After removal from the body, muscles remain in a state of rest, inasmuch as they possess no spontaneity ot action. Though consisting of a highly irritable tissue, they cannot pass from the passive to the active state except upon the application of some form of stimulation.

The stimuli which are capable of calling forth a contraction may be divided into:

1. Mechanical. 2. Chemic. 3. Physical. 4. Electric.

Every mechanical stimulus of a muscle—*e.g.*, pick, cut, or tap—provided it has sufficient intensity, and is repeated with sufficient rapidity, will cause not only a single contraction, but a series of contractions.

All chemic agents which impair the chemic composition of the muscle with sufficient rapidity—*e.g.*, hydrochloric acid, acetic and oxalic acids, distilled water injected into the vessels, etc.—act as stimuli, and produce single and multiple contractions. Physical agents, as heat and electricity, also act as stimuli. A muscle heated rapidly to 30°C. contracts vigorously, and reaches its maximum at 45°C. Of all forms of stimuli, the electric is the most generally used. Two forms are used—the induced current and the make-and-break of a constant current.

Changes in a Muscle During Contraction.—When a muscle is stimulated, either indirectly through the nerve or directly by any external agent, it undergoes a series of changes, which relate to its form, volume, optic, physical chemic, and electric properties. These changes, in their totality, constitute the muscular contraction.

1. *Form.*—The most obvious change is that of form. The fibers become shorter in their longitudinal and wider in their transverse diameters, and the muscle as a whole becomes shorter and thicker. The degree of shortening may amount to thirty per cent. of the original length.

2. *Volume.*—The increase in transverse diameter does not fully compensate for the diminution in length, for there is at the moment of contraction a slight shrinkage in volume, which has been attributed to a compression of air in its interstices.

3. *Optic Changes.*—If a muscle-fiber be examined microscopically during its contraction, it will be observed that when the contraction wave begins, both bright and dim bands diminish in height and become broader, though this change is more noticeable in the region of the bright band. This Englemann attributes to a passage of fluid material from the bright

into the dim band. At the time of relaxation there is a return of this material, and the fiber assumes its original shape and volume. As the contraction wave reaches its maximum, the optic properties of both the isotropic and anisotropic bands change. The *former*, which was originally clear, now becomes darker and less transparent, until at the crest of the wave it assumes the appearance of a distinct dark band. The *latter*, the anisotropic, which was originally dim, now becomes, in comparison, clear and light. This change in optic appearance is due to an increase in refrangibility of the isotropic and a decrease in the anisotropic bands coincident with the passage of fluid from the former into the latter. There is at the height of the contraction a complete reversal in the positions of the striations. At a certain stage between the beginning and the crest of the wave there is an intermediate point, at which the striæ almost entirely disappear, giving to the fiber an appearance of homogeneity. There is, however, no change in refractive power, as shown by the polarizing apparatus. After the contraction wave has reached the stage of greatest intensity, there is a reversal of the foregoing phenomena, and the fiber returns to its original condition, which is one of relaxation.

4. *Physical Changes.*—The extensibility of muscle is increased during the contraction, the same weight elongating the fibers to a greater extent than during rest. The elasticity, or its power of returning to its original form, is correspondingly diminished.

5. *Chemic Changes.*—The chemic changes which take place in a muscle during contraction or activity are very complex.

As shown by an analysis of the blood flowing to and from the resting muscle, it has, while passing through the capillaries, lost oxygen and gained carbon dioxid. The amount of oxygen absorbed by the muscle (nine per cent.) is greater than the amount of CO_2 given off (6.7 per cent.). There is no parallelism between these two processes, as CO_2 will be given off in the absence of oxygen, or in an atmosphere of nitrogen.

In the active or contracting muscle both the absorption of oxygen and the production of CO_2 are largely increased, but the ratio existing between them differs considerably from that of the resting muscle, for the quantity of oxygen absorbed amounts to 11.26 per cent., the quantity of CO_2 to 10.8 per cent. (Ludwig). Moreover, in a tetanized muscle the quantity of CO_2 given off may be largely in excess of the oxygen absorbed. From these facts it is evident that the energy of the contraction does not depend upon the direct oxidation of certain substances, but upon the decomposition of some unstable compound of high potential energy, rich in carbon and oxygen. When the muscle is active, its tissue changes from a neutral to an acid reaction, from the development of sarcolactic and possibly phosphoric acids. The amount of glycogen present in muscle (0.43 per cent.) diminishes, but muscles wanting in glycogen, nevertheless, retain their power of contraction. Water is absorbed. The amount of urea is not materially increased by muscular activity, unless it is excessive and prolonged, and then only in the absence of a sufficient quantity of non-nitrogenized material. Coincident with muscle contraction, the blood-vessels become widely dilated, leading to a large increase in the blood-supply and a rapid removal of products of decomposition.

Thermic Changes.—Coincident with the foregoing chemic changes and the transformation of energy, there is a liberation of heat and a rise in the temperature of the muscle. A single contraction of the gastrocnemius muscle of the frog, will raise its temperature 0.001°C.

Electric phenomena also manifest themselves which are similar to the electric phenomena presented by nerves and will be alluded to in a subsequent section.

Transmission of the Contraction Wave.—Normally, when a muscle is stimulated by the nerve impulse, the shortening and thickening of the fibers begin at the end organ and travel in opposite directions to the ends of the muscle. This change propagates itself in a wave-like manner, and has been termed the contraction wave. If a stimulus be applied directly to the end of a long muscle, the contraction wave passes along its entire length to the opposite extremity, in virtue of the conductivity of muscular tissue. The rapidity of the propagation varies in different animals—in the frog, from three to four meters a second, in man, from ten to thirteen meters. The length of the wave varies from 200 to 400 millimeters.

Graphic Record of a Muscle Contraction.—The changes in the form of a muscle during contraction and relaxation have been carefully studied by recording the muscle movement by means of an attached lever, the end of which is allowed to rest upon a moving surface. The time relations of all phases of the muscular movement are obtained by placing beneath the lever a pen attached to an electro-magnet thrown into action by a tuning-fork vibrating in hundredths of a second. A marking lever records simultaneously the moment of stimulation.

Single Contraction.—When a single electric induction shock is applied to a nerve close to the muscle, the latter undergoes a quick pulsation, speedily returning to its former condition. As shown by the muscle curve (see Fig. 1) there is between the moment of stimulation and the beginning of the contraction a short but measurable period, known as the *latent period*, during which certain chemic changes are taking place preparatory to the exhibition of the muscle movement. Even when the electric stimulus is applied directly to the muscle, a latent period, though shorter, is observable. The duration of this period in the skeletal muscles of the frog has been estimated at 0.01 of a second; but it has been shown by the employment of more accurate methods and the elimination of various external influences to be much less—not more than 0.0033 to 0.0025 of a second.

The *contraction* follows the latent period. This begins slowly, rapidly reaches its maximum, and ceases. This has been termed the stage of rising or increasing energy. The time occupied in the stage of shortening is about 0.04 of a second, though this will depend on the strength of the stimulus, the load with which the muscle is weighted, and the condition of the muscle irritability.

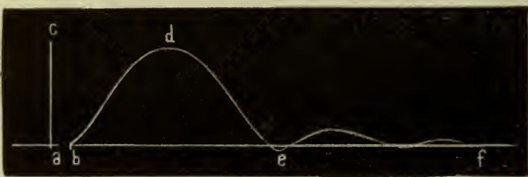

FIG. 1.—MUSCLE CURVE PRODUCED BY A SINGLE INDUCTION SHOCK APPLIED TO A MUSCLE.—(*Landois.*)
a–f. Abscissa. a–c. Ordinate. a–b. Period of latent stimulation. b–d. Period of increasing energy. d–e. Period of decreasing energy. e–f. Elastic after-vibrations.

The *relaxation* immediately follows the contraction. This takes place at first slowly, after which the muscle rapidly returns to its original length. This is the period of falling or decreasing energy, and occupies about 0.05 of a second. The whole duration of a muscle contraction occupies, therefore, about 0.1 of a second.

Residual or after-vibrations are frequently seen which are due to changes in the elasticity of the muscle. The *amplitude* of the contraction depends upon the condition of the muscle, the load, the strength of stimulus, etc.

Action of Successive Stimuli.—If a series of successive stimuli be applied to a muscle, the effect will be different according to the rapidity with which they follow one another. If the second stimulus be applied at the termination of the contraction due to the first stimulus, a second contraction follows, similar in all respects to the first. A third stimulus produces a third contraction, and so on until the muscle becomes exhausted. If the second stimulus be applied during either of the two periods of the first contraction, the effects of the two stimuli will be added together and the second contraction will add itself to the first. The maximum contraction is obtained when the second stimulus is applied $\frac{1}{20}$ of a second after the first.

Tetanus.—Tetanus may be defined as a more or less continuous contraction of a muscle which arises when the time intervals between the stimuli are shorter than the time of the contraction process. Tetanus will be incomplete or complete according to the number of stimuli that reach the muscle in a second of time. When a muscle is stimulated directly or, better, indirectly through its related nerve by a series of induced currents at the rate of four or six per second, it undergoes a corresponding number of contractions of about equal extent. If the rate of stimulation is increased up to the point when the interval between each stimulus is less than the duration of the entire contraction process, the muscle does not have time to relax completely before the arrival of the succeeding stimulus, and hence remains in a more or less contracted state, during which it exhibits a series of alternate partial contractions and relaxations. To this condition of muscle activity the term incomplete tetanus or clonus is applied.

If the stimulation be still further increased in frequency, the individual contractions become fused together and the curve described by the lever becomes a continuous line. Notwithstanding the fact that the individual contractions are no longer visible, it can be shown by other methods that the muscle is undergoing a series of slight alternate contractions and relaxations or vibrations at least. After a varying length of time the muscle becomes fatigued, relaxes, and returns to its natural condition even though the stimulation be continued. The number of stimuli per second necessary to develop complete tetanus will depend under normal circumstances on the period of duration of the individual contractions. The longer this period, the less the number of stimuli required, and the reverse. Hence the number of stimuli will vary for different classes of animals and for different muscles in the same animal, *e.g.*, 2 or 3 for the muscles of the tortoise, 10 for the muscles of the rabbit, 15 to 20 for the frog, 70 to 80 for birds, 330 to 340 for insects.

Physiologic Tetanus.—A physiologic tetanus of longer or shorter duration may be established by an act of volition or by the action of some external stimulus. In the first instance the tetanus is termed volitional and in the second instance, reflex.

1. *Volitional tetanus.* As the volitional contraction is similar to that observed when a muscle or its related nerve is stimulated by rapidly repeated induced currents, it is assumed that the nerve-cells in the spinal cord are discharging in a rhythmic manner a certain number of nerve impulses per second in consequence of the arrival of nerve impulses coming from the cerebral cortex, the result of volitional acts. In other words the volitional tetanus is the result of a discontinuous stimulation. The number of stimuli transmitted to a muscle during a volitional tetanus has been estimated by the employment of the graphic method at from 8 to 13 per second, 10 being about the average. When a volitional contraction is recorded the myogram not infrequently exhibits a series of small wave-like elevations which indicate that the muscle is not in a state of complete tetanus but is undergoing slight alternate contractions and relaxations. Unless the contraction process in human muscle differs from that of frogs it is difficult to see how 10 or even 20 stimuli per second can give rise to even an incomplete tetanus when the single contraction is $\frac{1}{20}$ of a second in duration.

2. *Reflex.*—A tetanus of muscle, physiologic in character, arises during the performance of many muscle movements in consequence of peripherally acting causes and may therefore be termed a reflex tetanus. The duration of a tetanus thus induced, like the duration of a volitional tetanus, will vary with the duration of the exciting cause. Reflex tetani are presented by the muscles of the lower jaw during mastication, by the intercostal muscles during breathing, by the muscles of the limbs during walking, etc. In these and other instances there are reasons for believing that for a variable period of time the muscles are in a state of continuous contraction from the discharge of nerve impulses from the nerve cells in the spinal cord as the result of the arrival of nerve impulses coming from a peripheral surface.

A non-physiologic tetanus may be excited or developed by the action of pharmacologic agents, *e.g.*, strychnin, and of pathologic agents, *e.g.*, toxins developed by bacteria, acting on the spinal cord mechanisms.

Muscle Fatigue.—Prolonged or excessive muscular activity is followed by a diminution in the power of performing work and by an increase in the duration of the muscular contractions. Fatigue is accompanied by a feeling of stiffness, soreness, and lassitude, referable to the muscles themselves. In the early stages of muscular fatigue the contractions increased in height and duration, to be followed by a progressive decrease in height, but an increase in duration, until the muscle becomes exhausted. The cause of the fatigue is the production and accumulation of decomposition products, such as phosphoric acid and phosphate of potassium, CO_2, etc. A fatigued muscle is rapidly restored by the injection of arterial blood.

The Source of the Energy and the Nature of the Muscle Contraction.—The passage of a nerve impulse into a muscle together with its subsequent action, calls forth a pulsation, which is attended with the production of lactic acid, carbon-dioxid and water and the liberation of heat. These phenomena would indicate that some compound had undergone an oxidation in whole or in part. The exact chemic nature of the compound has however not been determined. Whatever the nature of the compound the problem requiring solution is how do the chemic changes and the concomitant liberation of energy cause the muscle to contract. The latest explanation is that of Hill. This investigator assumes that there is primarily in the muscle a complex compound the exact nature of which has not been determined but which contains potential energy. The arrival of the nerve impulse leads to a disruption of this compound with the liberation of lactic acid. The acid at once acidifies the sarcous elements and in so doing endows them with the power of imbibing water from the sarcoplasm, whereupon they swell and tend to approximate a spherical shape and thus shorten the muscle. Following the contraction or the shortening, there occurs an oxidation of sugar with the production of carbon dioxid and water and the liberation of heat. A portion of the heat is then utilized in the re-formation or reconstruction of the compound. The lactic acid is again incorporated in whole or in part and the heat absorbed is transformed into potential or chemical energy. With the withdrawal of the acid, the sarcous elements lose their imbibition power and the fluid returns to the surrounding sarcoplasm.

The Production of Heat and Its Relation to Mechanical Work.—The transformation of energy which takes place during a muscle contraction, and which is dependent upon chemic changes occurring at that time, manifests itself as heat and mechanical work. While heat is being evolved continuously during the passive condition of muscles, the amount of heat is largely increased during general muscle contraction. A skeletal muscle of a frog—*e.g.*, the gastrocnemius—when removed from the body, shows, after tetanization, an increase in its temperature of from 0.14° to 0.18°C., and after a single contraction of from 0.001° to 0.005°C. While every muscular contraction is attended by an increase in heat production, the amount so produced will vary in accordance with certain conditions—*e.g.*, tension, work done, fatigue, circulation of blood, etc.

Tension.—The greater the tension of a muscle, the greater, other conditions being equal, is the amount of heat evolved. When the ends of a muscle are fastened so that no shortening is possible during stimulation, the maximum of heat production is reached. In the tetanic state the great increase of temperature is due to the tension of antagonistic and strongly contracted muscles. The evolution of heat, therefore, bears a relation to the resistance against which the muscle is acting.

Mechanical Work.—If a muscle contracts, loaded by a weight just sufficient to elongate it to its original length, heat is evolved, but no mechanical work is done, all the energy liberated manifesting itself as heat. When the weight which has been lifted is removed from the muscle at the height of contraction, external work is done. In this case the amount of heat liberated is less, owing to the work done, for some of the heat generated is transformed into mechanical motion. According to the law of the conservation of energy, the amount of heat disappearing should correspond in heat units to the number of foot-pounds produced by muscular contraction.

Work Done.—Muscles are machines capable of doing a certain amount of work, by which is meant the raising of a weight against gravity or the overcoming of some resistance. The work done is calculated by multiplying the weight by the distance through which it is raised. Thus, if a muscle shortens four millimeters and raises 250 grams, it does work equal to 1,000 milligrammeters, or one gram-meter. If a muscle contracts without being weighted, no work is done. Equally, when the muscle is over-weighted so that it is unable to contract, no work is done. The amount of work a muscle can do will depend upon the area of its transverse section, the length of its fibers, and the amount of the weight. The amount of work a laborer of 70 kilograms weight performs in eight hours averages 105,605 kilogram-meters, or 340.2 foot-tons.

Muscle Sound.—Providing a muscle be kept in a state of tension during its contraction, the intermittent variations of its tension cause the muscle to emit an audible sound. If the muscle be tetanized by induction shocks, the pitch of the sound corresponds with the number of stimuli a second. A voluntary contraction is attended by a tone having a vibration frequency of about thirty-six a second, which is, however, the first overtone of the true muscle tone, which is caused by a contraction frequency of about eighteen a second. This low tone is inaudible, from the small number of vibrations a second.

Rigor Mortis.—A short time after death the muscles pass into a condition of extreme rigidity or contraction, which lasts from one to five days. In this state they offer great resistance to extension, their tonicity disappears, their cohesion diminishes, their irritability ceases. The time of the appearance of this post-mortem or cadaveric rigidity varies from a quarter of an hour to seven hours. Its onset and duration are influenced by the condition of the muscular irritability at the time of death. When the irritability is impaired from any cause, such as disease or defective blood-supply, the rigidity appears promptly, but is of short duration. After death from acute diseases, it is apt to be delayed, but to continue for a longer period.

The rigidity appears first in the muscles of the lower jaw and neck; next in the muscles of the abdomen and upper extremities; finally in the trunk and lower extremities. It disappears in practically the same order.

Chemic changes of a marked character accompany this rigidity. The muscle becomes acid in reaction from the development of sarcolactic acid; it gives off a large quantity of carbonic acid, and is shortened and diminished in volume.

The immediate cause of the rigidity appears to be a coagulation of the *myosinogen* within the sarcolemma, with the subsequent formation of *myosin* and muscle serum. In the early stages of coagulation restitution is possible by the circulation of arterial blood through the vessels. The final disappearance of this contraction is due to the action of acids dissolving the myosin, and possibly to putrefactive changes.

The Visceral Muscle.—The visceral muscle, as the name implies, is found in the walls of hollow viscera, where it is arranged in the form of a membrane or sheet. It is present in the walls of the alimentary canal, blood-vessels, respiratory tract, ureter, bladder, vas deferens, uterus, fallopian tubes, iris, etc. In some situations it is especially thick and well developed—*e.g.*, uterus and pyloric end of the stomach; in others it is thin and slightly developed.

The Histology of the Visceral Muscle-fiber.—When examined with the microscope, the muscle sheet is seen to be composed of fibers, narrow, elongated, and fusiform in shape. As a rule, they are extremely small, measuring only from 40 to 250 micromillimeters in length and from 4 to 8 micromillimeters in breadth. The center of each fiber presents a narrow, elongated nucleus. The muscle-protoplasm which makes up the body of the fiber appears to be enclosed by a delicate elastic membrane resembling in some respects the sarcolemma of the skeletal muscle. In some animals the visceral fiber presents a longitudinal striation suggesting the existence of fibrillæ surrounded by sarcoplasm. The fibers are united longitudinally and transversely by a cement material. The muscle is increased in thickness by the superposition of successive layers. At varying intervals the fibers are grouped into bundles or fasciculi by septa of connective tissue. Blood-vessels ramify in the connective tissue and furnish the necessary nutritive material.

The visceral muscle receives stimuli from the spinal cord, not directly, however, as in the case of the skeletal muscle, but indirectly through the intermediation of ganglion cells, which may be located at some distance from the muscle or near the walls of the viscera. Non-medullated fibers from the ganglion pass directly into the muscle, where they frequently unite to form a general plexus. From this plexus fine branches take their origin and ultimately become physiologically associated with the muscle-fiber.

Physiologic Properties.—The physiologic properties of visceral muscles are tonicity, elasticity, conductivity and irritability, properties which closely resemble the corresponding properties of the skeletal muscles.

A *contraction* of the visceral muscle can be called forth by the passage of a single induced current and which can be graphically recorded. The duration of the contraction is, however, very much longer than the duration of the skeletal muscle contraction; thus the period of shortening may last for five seconds and the period of relaxation for as much as thirty-five seconds. The muscle can also be tetanized. Moreover it will respond to variations in temperature, strength of stimulus, to the load in a manner similar to if not identical with the skeletal muscle.

The Function of the Visceral Muscle.—In a general way it may be said that the visceral muscle determines and regulates the passage through the viscus or organ of the material contained within it. The food in the stomach and intestines is subjected to a churning process by the muscles, in consequence of which the digestive fluids are more thoroughly incorporated and their characteristic action increased. At the same time the food is carried through the canal, the absorption of the nutritive material promoted, and the indigestible residue removed from the body. The blood is delivered in larger or smaller volumes according to the needs of the tissues through a relaxation or contraction of the muscle-fibers of the blood-vessels. The urine is forced through the ureter and from the bladder by the contraction of their respective muscles. The mode of action of the individual muscles will be described in subsequent chapters.

SPECIAL PHYSIOLOGY OF MUSCLES

The individual muscles of the axial and appendicular portions of the body are named with reference to their shape, action, structure, etc.—*e.g.*, deltoid, flexor, penniform, etc. In different localities a group of muscles having a common function is named in accordance with the kind of motion it produces or gives rise to —*e.g.*, groups of muscles which alternately bend or straighten a joint or alternately diminish or increase the angular distance between two bones, are known, respectively, as *flexors* and *extensors;* such muscle groups are in association with ginglymus joints. Muscles which turn the bone to which they are attached around its own axis without producing any great change of position are known as *rotators*, and are in association with the enarthrodial or ball-and-socket joints. Muscles which impart an angular movement of the extremities to and from the median line of the body are termed *abductors* and *adductors*.

In addition to the actions of individual groups of muscles in causing special movements in some regions, several groups of muscles are coördinated for the accomplishment of certain definite functions—*e.g.*, muscles of respiration, mastication, expression. The coördination of axial and appendicular muscles enables the individual to assume certain postures, such as standing and sitting; to perform various acts of locomotion, as walking, running, swimming, etc.

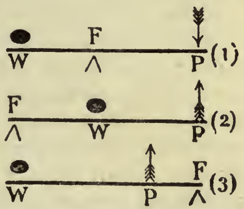

FIG. 2.—THE THREE ORDERS OF LEVERS.

Levers.—The function or special mode of action of individual muscles can be understood only when the bones with which they are connected are regarded as levers whose fulcra or fixed points lie in the joints where the movement takes place, and when the muscles are considered as sources of power for imparting movement to the levers, with the object of overcoming resistance or raising weights.

In mechanics, levers of three kinds or orders are recognized, according to the relative position of the *fulcrum* or axis of motion, the applied power, and the weight to be moved. (See Fig. 2.)

In levers of the *first order* the fulcrum, F, lies between the weight or resistance, W, and the power of moving force, P. The distance P–F is known as the power arm, the distance W–F as the weight arm. As an example of this form of lever in the human body may be mentioned:

1. The elevation of the trunk from the flexed position. The axis of movement, the fulcrum, lies in the hip-joint; the weight, that of the trunk, acting as if concentrated at its center of gravity, lies between the shoulders; the power, the contracting muscles attached to the tuberosity of the ischium. The opposite movement is equally one of the first order, but the relative positions of P and W are reversed.

2. The skull in its movements backward and forward upon the atlas.

In levers of the *second order* the weight lies between the power and the fulcrum. As an illustration of this form of lever may be mentioned:

1. The depression of the lower jaw, in which movement the fulcrum is the temporomaxillary articulation; the resistance, the tension of the elevator muscles; the power, the contraction of the depressor muscles.

2. The raising of the body on the toes—F being the toes, W the weight of the body acting through the ankle, P the gastrocnemius muscle acting upon the heel bone.

In levers of the *third order* the power is applied at a point lying between the fulcrum and the weight. As examples of this form of lever may be mentioned:

1. The flexion of the forearm—F being the elbow-joint, P the contracting biceps and brachialis anticus muscles applied at their insertion, W the weight of the forearm and hand.

2. The extension of the leg on the thigh.

When levers are employed in mechanics, the object aimed at is the overcoming of a great resistance by the application of a small force acting through a great distance, so as to obtain a mechanical advantage. In the mechanism of the human body the reverse generally obtains—viz., the overcoming of a small resistance by the application of a great force acting through a small distance. As a result, there is a gain in the extent and rapidity of movement of the lever. The power, however, owing to its point of application, acts at a great mechanical disadvantage in many instances, especially in levers of the third order.

Postures.—Owing to its system of joints, levers, and muscles, the human body can assume a series of positions of equilibrium, such as standing, and sitting, to which the name posture has been given. In order that the body may remain in a state of stable equilibrium in any posture, it is essential that the vertical line passing through the center of gravity shall fall within the base of support.

Standing is that position of equilibrium in which a line drawn through the center of gravity falls within the area of both feet placed on the ground. This position is maintained:

1. By firmly fixing the head on top of the vertebral column by the action of the muscles on the back of the neck.

2. By making the vertebral column rigid, which is accomplished by the longissimus dorsi and the quadratus lumborum muscles. This having been accomplished, the center of gravity falls in front of the tenth dorsal vertebra; the vertical line passing through this point falls behind the line connecting both hip-joints. In consequence, the trunk is not balanced

on the hip-joints, and would fall backward were it not prevented by the contraction of the rectus femoris muscle and ligaments. At the knees and ankles a similar balancing of the parts bove is brought about by the action of various muscles. When the entire body is in the erect or military position, the arms by the sides, the center of gravity lies between the sacrum and the last lumbar vertebra, and the vertical line touches the ground between the feet and within the base of support.

Sitting erect is a condition of equilibrium in which the body is balanced on the tubera ischii, when the trunk and head together form a rigid column. The vertical line passes between the tubera.

Locomotion is the act of transferring the body, as a whole, through space, and is accomplished by the combined action of its own muscles. The acts involved consist of walking, running, jumping, etc.

Walking is a complicated act, involving almost all the voluntary muscles of the body, either for purposes of progression or for balancing the head and trunk, and may be defined as a progression in a forward horizontal direction, due to the alternate action of both legs. In walking, one leg becomes for the time being, the active or supporting leg, carrying the trunk and head; the other, the passive but progressive leg, to become in turn the active leg when the foot touches the ground. Each leg, therefore, is alternately in an active and a passive state.

Running is distinguished from walking by the fact that, at a given moment, both feet are off the ground and the body is raised in the air.

While the limits of a compend do not permit of a description of the origin, insertion, and mode of action of the individual muscles of the body, it has been thought desirable to call attention to a few of the principal muscles whose function it is to produce special forms of movement, as well as locomotion (See Fig. 3). The erect position is largely maintained by the fixation of the spinal column and the balancing of the head upon its upper extremity; the former is accompanied by the *erector spinæ* muscle, named from its function and its fleshy continuations, situated on each side of the vertebral column. Arising from the pelvis and lumbar vertebræ, this muscle passes upward, and is attached by its continuations to all the vertebræ. Its action is to extend the vertebral column and to maintain the erect position. The head is balanced upon the top of the vertebral column by the combined action of the trapezius and suboccipital muscles forming the nape of the neck, and by the *sterno-cleido-mastoid* muscle. This latter muscle arises from the inner third of the clavicle and upper border of the sternum. It is inserted into the temporal bone just behind the ear. Its action is to flex the head laterally

FIG. 3.—SUPERFICIAL MUSCLES OF THE BODY.

and to rotate the face to the opposite side. When both muscles act simultaneously, the head and neck are flexed upon the thorax.

The *temporal* and *masseter* muscles, situated at the side of the head, arise respectively from the temporal fossa and the zygomatic arch, and are inserted into the ramus of the lower jaw. Their action is to close the mouth and to assist in mastication. The *occipito-frontalis*, the *orbicularis palpebrarum*, and *orbicularis oris* muscles are largely concerned in wrinkling the forehead, closing the eyes and mouth, and in giving various expressions to the face.

The *deltoid* is a thick, triangular muscle covering the shoulder-joint. Arising from ths outer third of the clavicle, the acromial process, and the spine of the scapula, its fibers converge to be inserted into the humerus just above its middle point. Its action is to elevate the arm through a right angle. Owing to its point of insertion it acts as a lever of the third order, but, notwithstanding the advantageous points of insertion, it acts at a considerable disadvantage, owing to the obliquity of its direction.

The *biceps* muscle, situated on the anterior aspect of the arm, arises from the upper border of the glenoid fossa and the coracoid process, and is inserted into the radius just beyond the elbow-joint. Its action is to flex and supinate the forearm and to place it in the most favorable position for striking a blow. When the forearm is fixed, it assists in flexing the arm, as in climbing.

The *triceps* muscle, situated on the back of the arm, arises from the scapula and the posterior surface of the humerus, and is inserted in the olecranon process of the ulna. In its action it directly antagonizes the biceps, namely, extending the forearm. In so doing it acts as a lever of the first order. The short distance between the muscular insertion and the fulcrum causes it to act at a great mechanical disadvantage, but there is a corresponding gain in both speed and range of movement. The muscles of the forearm are very numerous. Their action is to impart to the forearm and hand a variety of movements, such as pronation, supination, flexion, extension, rotation, etc.

The *pectoralis major* and *pectoralis minor* muscles form the fleshy masses of the breast. Arising from the inner half of the clavicle, the side of the sternum, and the outer surfaces of the third, fourth, and fifth ribs anteriorly, the muscle-fibers converge to be inserted into the humerus and coracoid process. Their combined action is to adduct, flex and rotate the arm inward and to draw the scapula downward and forward, movements necessary to the folding of the arms across the chest.

The *rectus abdominis* and the *obliquus externus* assist in forming the abdominal walls.

The *glutei* muscles are three in number, are arranged in layers, and form the fleshy masses known as the buttocks. They arise from the side of the pelvis and are attached to the femur in the neighborhood of the great trochanter. Their action is to extend the hips, to raise the body from the stooping position, and to assist in walking by firmly holding the pelvis on the thigh while the opposite leg is advanced in the forward direction.

The rectus femoris, with its associates, the vastus internus and vastus externus and the crureus, forms the fleshy mass on the anterior surface of the thigh. The former arises from the anterior part of the ilium, the latter from the femur. Their common tendon, which is united to the patella, is continued as the ligamentum patellæ, which is attached to the upper part of the tibia. The action of this muscular group is to extend the leg, to flex the thigh, and to raise the entire weight of the body, as in changing from the sitting to the erect position.

The *biceps femoris* muscle, situated on the outer and posterior aspect of the thigh, arises from the tuber ischii, and is inserted into the head of the fibula.

The *semimembranosus* and the *semitendinosus* muscles, situated on the inner and posterior aspect of the thigh, are inserted into the head of the tibia. Their combined action is to extend the hips and to flex the knee. Acting from below, they assist in raising the body from the stooping position.

The *gastrocnemius* muscle forms the enlargement known as the calf of the leg. It arises by two heads from the condyles of the femur. Its tendon, the tendo Achillis, is inserted into the posterior surface of the heel bone. Its action is to extend the foot and to raise the weight of the body in walking and running. On the front of the leg are numerous muscles—*e.g.*, *tibialis anticus*, *peroneus longus*, *etc.*, the action of which is to flex the foot and to antagonize the gastrocnemius.

PHYSIOLOGY OF NERVE TISSUE

The **nerve tissue**, which unites and coördinates the various organs and tissues of the body and brings the individual into relationship with the external world, is arranged anatomically into two systems, termed the *encephalo* or *cerebro-spinal* and the *sympathetic*.

The **encephalo-spinal** or **cerebro-spinal system** consists of:

1. The brain and spinal cord, contained within the cavities of the cranium and the spinal column respectively, and

2. The cranial and spinal nerves.

The **sympathetic system** consists of:

1. A double chain of ganglia situated on each side of the spinal column and extending from the base of the skull to the tip of the coccyx.

2. Various collections of ganglia situated in the head, face, thorax, abdomen, and pelvis. All these ganglia are united by an elaborate system of intercommunicating nerves, many of which are connected with the cerebro-spinal system.

HISTOLOGY OF NERVE TISSUE

The Neuron.—The nerve tissue has been resolved by the investigations of modern histologists into a single morphologic unit, to which the term neuron has been applied. The entire nervous system has been shown to be but an aggregate of an infinite number of neurons, each of which is histologically distinct and independent. Though having a common origin, as shown by embryologic investigations, they have acquired a variety of forms in different parts of the nervous system in the course of development. The old conception that the nervous system consists of two distinct histologic elements, nerve-cells and nerve-fibers, which differed not only in their mode of origin, but also in their properties, their relation to each other, and their functions, has been entirely disproved.

The neuron, or neurologic unit, is histologically a nerve-cell, the surface of which presents a greater or less number of processes in varying degrees of differentiation. As represented in figure 7, the neuron may be said to consist of: (1) The nerve-cell, neurocyte, or corpus; (2) the axon, or nerve process; (3) the end tufts, or terminal branches. Though these three main histologic features are everywhere recognizable, they exhibit a variety of secondary features in different situations in accordance with peculiarities of function. Though the nerve-cell and the nerve-fiber are but part of the same neuron, it is convenient at present to describe them separately.

The Nerve-cell.—The nerve-cell, or body of the neuron, presents a variety of shapes and sizes in different portions of the nervous system. Originally ovoid in shape, it has acquired, in course of development, peculiarities of form which are described as pyramidal, stellate, pear-shaped, spindle-shaped, etc. The size of the cell varies considerably, the smallest having a diameter of not more than $\frac{1}{3000}$ of an inch, the largest not more than $\frac{1}{400}$ of an inch. Each cell consists of granular striated protoplasm, containing a distinct vesicular nucleus and a well-defined nucleolus. A cell membrane has not been observed. From the surface of the adult cell portions of the protoplasm are projected in various directions, which portions, rapidly dividing and subdividing, form a series of branches, termed *dendrites* or *dendrons*. In some situations the ultimate branches of the dendrites present short lateral processes, known as *lateral buds*, or *gemmules*, which impart to the branches a feathery appearance. This characteristic is common to the cells of the cortex, of the

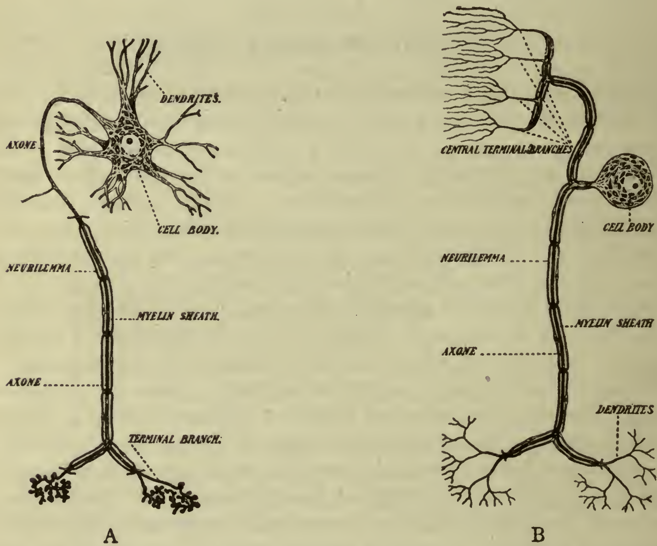

FIG. 4.—A. EFFERENT NEURON; B, AFFERENT NEURON. FOUND IN BOTH SPINAL AND CRANIAL NERVES.

cerebrum, and of the cerebellum. The ultimate branches of the dendrites, though forming an intricate feltwork, never anastomose with one another, nor unite with dendrites of adjoining cells. According to the number of axons, nerve-cells are classified as monaxonic, diaxonic, polyaxonic. Most of the cells of the nervous system of the higher vertebrates are monaxonic. In the ganglia of the posterior or dorsal roots of the spinal and cranial nerves, however, they are diaxonic. In this situation the axons, emerging from opposite poles of the cell, either remain separate and pursue opposite directions, or unite to form a common stem, which subsequently divides into two branches, which then pursue opposite directions. (See Fig. 4.) The nerve-cell maintains its own nutrition, and presides over that of the dendrites and the axon as well. If the latter be separated in any part of its course from the cell, it speedily degenerates and dies.

The *axon*, or *nerve process*, arises from a cone-shaped projection from the surface of the cell, and is the first outgrowth from its protoplasm. At a short distance from its origin it becomes markedly differentiated from the dendrites which subsequently develop. It is characterized by a sharp, regular outline, a uniform diameter, and a hyaline appearance. In structure, the axon appears to consist of fine fibrillæ embedded in a clear, protoplasmic substance. Shäfer advocates the view that the fibrillæ are exceedingly fine tubes filled with fluid. The axon varies in length from a few millimeters to 100 cm. In the former instance the axon, at a short distance from its origin, divides into a number of branches, which form an intricate feltwork in the neighborhood of the cell. In the latter instance the axon continues for an indefinite distance as an individual structure. In its course, however, especially in the central nervous system, it gives off a number of *collateral* branches, which possess all its histologic features. The long axons seem to bring the body of the cell into direct relation with peripheral organs, or with more or less remote portions of the nervous system, thus constituting association or commissural fibers.

The more or less elongated axon becomes invested, as a rule, at a short distance from the cell with nucleated oblong cells, which subsequently become modified and constitute a medullary or myelin sheath. This is invested by a thin, cellular membrane—the neurilemma. These three structures thus constitute what is known as a medullated nerve-fiber. In the central nervous system the outer sheath is frequently absent. In the sympathetic system the myelin is frequently absent, though the axon is inclosed by the neurilemma, thus constituting a non-medullated nerve-fiber.

The *end tufts* or *terminal organs* are formed by the splitting of the axon into a number of filaments, which remain independent of one another and are free from the medullary investment. The histologic peculiarities of the terminal organs vary in different situations, and in many instances are quite complex and characteristic. In peripheral organs, as muscles, glands, blood-vessels, skin, mucous membrane, the tufts are in direct organic connection with their cellular elements. In the central nerve system the tufts are in more or less intimate relation with the dendrites of adjacent neurons.

The neurons in their totality constitute the neuron or nerve tissue.

From the fact that they are arranged both serially and collaterally into a regular and connected whole, they collectively constitute the system known as the *neuron* or *nerve* system. The neurons moreover are grouped into more or less complexly organized masses termed organs which in accordance with their actions may be divided for convenience into central and peripheral organs.

The Central Organs of the Nerve System.—The central organs consist of the encephalon and spinal cord, contained within the cavities of the head and spinal column respectively. They consist of neurons arranged in a very complex manner. In a subsequent chapter the anatomic arrangement of their constituent parts will be detailed.

The Peripheral Organs of the Nerve System.—These consist of the cranial and spinal nerves and the sympathetic ganglia. Each nerve consists of a variable number of neurons united into firm bundles by con-

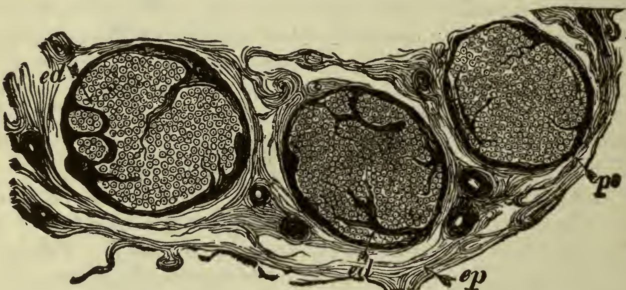

FIG. 5.—TRANSVERSE SECTION OF A NERVE (MEDIAN).
ep. Epineurium. *pe.* Perineurium. *ed.* Endoneurium.—(*Landois and Stirling.*)

nective tissue which supports blood-vessels and lymphatics. The bundles are technically known as *nerve-trunks* or *nerves*.

The nerve-trunks connect the brain and cord with all the remaining structures of the body. Each nerve is invested by a thick layer of lamellated connective tissue, known as the *epineurium*. A transverse section of a nerve shows (see Fig. 5), that it is made up of a number of small bundles of fibers each of which possesses a separate investment of connective tissue—the *perineurium*. Within this membrane the nerve-fibers are supported by a fine stroma—the *endoneurium*. After pursuing a longer or shorter course, the nerve trunk gives off branches, which interlace very freely with neighboring branches, forming plexuses, the fibers of which are distributed to associated organs and regions of the body.

From their origin to their termination, however, nerve-fibers retain their individuality, and never become blended with adjoining fibers.

As nerves pass from their origin to their peripheral terminations, they give off a number of branches, each of which becomes invested with a lamellated sheath—an offshoot from that investing the parent trunk. This division of nerve bundles and sheath continues throughout all the branches down to the ultimate nerve-fibers, each of which is surrounded by a sheath of its own, consisting of a single layer of endothelial cells. This delicate transparent membrane, the sheath of Henle, is separated from the nerve-fiber by a considerable space, in which is contained lymph destined for the nutrition of the fiber. Near their ultimate terminations the nerve-fibers themselves undergo division, so that a single fiber may give origin to a number of branches, each of which contains a portion of the parent axis-cylinder and myelin.

The neurons composing the spinal and cranial nerves are represented in Fig. 6, which are connected peripherally by their terminal branches with

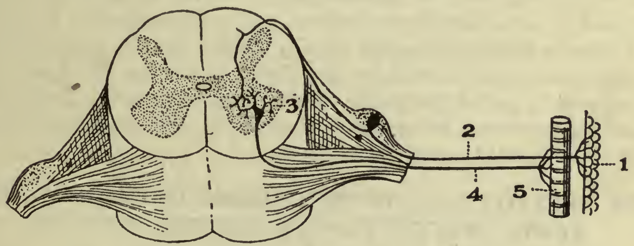

FIG. 6.—DIAGRAM OF A SIMPLE REFLEX ARC.
1. Sentient surface. 2. Afferent nerve. 3. Emissive or motor cell. 4. Efferent nerve. 5. Muscle.—(*After Morat and Dayon.*)

muscles on the one hand and with epithelium of skin, mucous membrane etc., on the other hand. In the spinal cord the terminal branches of the afferent neuron come into histologic and physiologic relation with the dendrites of a second neuron, the axonic process of which in many instances ascends the cord to different levels or even as far as the brain, where its terminal branches come into relation with the dendrites of still another neuron, the axonic process of which is in turn connected with neurons in the cortex of either the cerebrum or cerebellum. The surfaces of the body are thus brought into relation with the cerebral and cerebellar neurons. The neurons arranged in this serial manner constitute the *afferent* side of the nerve system.

In a similar way the efferent neurons of the spinal and cranial nerves are brought into relation with the cortex of the cerebrum. Large pyramidal-shaped neurocytes situated in specialized regions of the cortex of the cerebrum send their axonic processes down through the brain and cord. As they approach their destination the terminal branches become related histologically and physiologically with the dendrites of the neurons composing the cranial and spinal nerves. The cortex of the cerebrum is thus brought into relation with the general musculature of the body. The neurones arranged in this serial maner constitute the *efferent* side of the nerve system.

Sympathetic Ganglia.—A sympathetic ganglion consists essentially of a connective-tissue capsule with an interior framework. The meshes of this framework contain nerve-cells possessing dendrites and branching axons. The majority of the axons are devoid of myelin and are therefore known as non-myelineated nerve-fibers. Owing to the absence of the myelin they present a rather pale or grayish appearance. In all instances, with the exception of the ganglion cells of the heart, the axons are distributed to non-striated muscle tissue and to the epithelium of glands.

The nerve-cells of the ganglia are also in histologic connection with the terminal branches of certain fine medullated nerve-fibers which leave the spinal cord by way of the ventral roots of the spinal nerves. These nerve-fibers are designated *pre-ganglionic* fibers, while those emerging from the cells are designated *post-ganglionic* fibers.

THE RELATON OF THE PERIPHERAL ORGANS OF THE NERVE SYSTEM TO THE CENTRAL ORGANS

Spinal Nerves.—The nerves in connection with the spinal cord are thirty-one in number on each side. If traced toward the spinal column, it will be found that the nerve-trunk passes through an intervertebral foramen. Near the outer limits of the foramina each nerve-trunk divides into two branches, generally termed roots, one of which, curving slightly forward and upward, enters the spinal cord on its anterior or ventral surface, while the other, curving backward and upward, enters the spinal cord on its posterior or dorsal surface. The former is termed the anterior or ventral root; the latter, the posterior or dorsal root. Each dorsal root presents near its union with the ventral root a small ovoid grayish enlargement known as a ganglion. Both roots previous to entering the cord subdivide into from four to six fasciculi.

A microscopic examination of a cross-section of the spinal cord shows that the fibers of the ventral roots can be traced directly into the body of the nerve-cells in the ventral horns of the gray matter. The fibers of the dorsal roots are not so easily traced, for they diverge in several directions shortly after entering the cord. In their course they give off collateral branches which, in common with the main fiber, and in tufts which become associated with nerve-cells in both the ventral and dorsal horns of the gray matter.

Cranial Nerves.—The nerves in connection with the base of the brain are known as cranial nerves; some of these nerves present a similar ganglionic enlargement, and therefore may be regarded as dorsal nerves, while others may be regarded as ventral nerves. Their relations within the medulla oblongata are similar to those within the spinal cord.

Development and Nutrition of Nerves.—The **efferent nerve-fibers,** which constitute some of the cranial nerves and all the ventral roots of the spinal nerves, have their origin in cells located in the gray matter beneath the aqueduct of Sylvius, beneath the floor of the fourth ventricle and in the anterior horns of the gray matter of the spinal cord. These cells are the modified descendants of independent, oval, pear-shaped cells—the neuroblasts—which migrate from the medullary tube. As they approach the surface of the cord their axons are directed toward the ventral surface, which eventually they pierce. Emerging from the cord, the axons continue to grow, and become invested with the myelin sheath and neurilemma, thus constituting the ventral roots.

The afferent nerve-fibers, which constitute some of the cranial nerves and all the dorsal roots of the spinal nerves, develop outside of the central nervous system and only subsequently become connected with it. At the time of the closure of the medullary tube a band or ridge of epithelial tissue develops near the dorsal surface, which, becoming segmented, moves outward and forms the rudimentary spinal ganglia. The cells in this situation develop two axons, one from each end of the cell, which pass in opposite directions, one toward the spinal cord, the other toward the periphery. In the adult condition the two axons shift their position, unite, and form a T-shaped process, after which a division into two branches again takes place. In the ganglia of all the sensori-cranial and sensorispinal nerves the cells have this histologic peculiarity.

Efferent and Afferent Nerves.—Nerves are channels of communication between the brain and spinal cord, on the one hand, and the skeletal muscles, glands, blood-vessels, visceral muscles, skin, mucous membrane, etc., on the other. Some of the nerve-fibers serve for the transmission of nerve energy from the brain and spinal cord to certain peripheral organs, and so accelerate or retard, augment or inhibit their activities; others serve for the transmission of nerve energy from certain peripheral organs to the brain and spinal cord which gives rise to sensation or other modes of nerve activity. The former are termed *efferent* or *centrifugal,* the latter *afferent* or *centripetal* nerves. Experimentally it has been determined that the anterior or ventral roots contain all the *efferent* fibers, the posterior or dorsal roots all the *afferent* fibers.

The **efferent nerves** may be classified, in accordance with their distribution and the characteristic forms of activity to which they give rise, into several groups, as follows:

1. *Skeletal-muscle* or *motor* nerves, those which convey nerve energy or nerve impulses directly to skeletal-muscles and excite them to activity.

2. *Gland* or *secretor* nerves, those which convey nerve impulses to glands by way of ganglia and influence in one direction or another the degree of their activity. Those which cause the formation and discharge of the secretion peculiar to the gland are known as secreto-motor, while those which decrease or inhibit the secretion are known as secreto-inhibitor nerves.

3. *Vascular* or *vaso-motor* nerves, those which convey nerve impulses to the muscle-fibers of the blood-vessels and change in one direction or the other the degree of their natural contraction. Those which increase the contraction are known as vaso-constrictors or vaso-augmentors; those which decrease the contraction are known as vaso-dilatators or vaso-inhibitors. The nerves which pass to that specialized part of the vascular apparatus, the heart, transmit nerve impulses which on the one hand accelerate its rate or augment its force, and on the other hand inhibit or retard its rate and diminish its force. For this reasom they are termed cardiac nerves, one set oi which is known as cardio-accelerator and cardio-augmentor, the other as cardio-inhibitor nerves.

4. *Visceral* or *viscero-motor* nerves, those which transmit nerve impulses to the muscle walls of the viscera and change in one direction or another the degree of their contraction. Those which increase or augment the contraction are known as viscero-augmentor, while those which decrease or inhibit the contraction are known as viscero-inhibitor nerves.

5. *Hair bulb* or *pilo-motor* nerves, those which transmit nerve impulses to the muscle-fibers which cause an erection of the hairs.

Of the foregoing nerves the skeletal-muscle or motor nerves alone pass directly to the muscle. The gland, the vascular and the visceral nerves, all terminate at a variable distance from the peripheral organ around a local sympathetic ganglion, which in turn is connected with the peripheral organ. The former are termed pre-ganglionic, the latter post-ganglionic fibers.

The **afferent nerves** may also be classified, in accordance with their distribution and the character of the sensations or other modes of nerve activity to which they give rise, into several groups, as follows:

A. *Tegumentary* nerves, comprising those distributed to skin, mucous membranes and sense organs and which transmit nerve impulses from the periphery to the nerve centers. They may be divided into reflex and sensorifacient nerves.

  1. *Reflex* nerves, those which transmit nerve impulses to the spinal cord and medulla oblongata, where they give rise to different modes of nerve activity. They may be divided into:

     a. Reflex excitator nerves, which transmit nerve impulses which cause an excitation of nerve centers and, in consequence, increased activity of peripheral organs, *e.g.*, skeletal muscles, glands, blood-vessels and viscera.

     b. Reflex inhibitor nerves, which transmit nerve impulses which cause an inhibition of nerve centers and, in consequence, decreased activity of the peripheral organs. It is quite probable that one and the same nerve may subserve both sensation and reflex action, owing to the collateral branches which are given off from the afferent roots as they ascend the posterior column of the cord.

  2. *Sensorifacient* nerves, those which transmit nerve impulses to the brain where they give rise to conscious sensations. They may be sub-divided into:

     a. Nerves of special sense—*e.g.*, olfactory, optic, auditory, gustatory, tactile, thermal, pain, pressure—which give rise to correspondingly named sensations.

     b. Nerves of general sense—*e.g.*, the visceral afferent nerves—those which give rise normally to vague and scarcely perceptible sensations, such as the general sensations of well-being or discomfort, hunger, thirst, fatigue, sex, want of air, etc.

B. *Muscle* nerve, comprising those distributed to muscles and tendons and which transmit nerve impulses from muscles and tendons to the brain, where they give rise to the so-called muscle sensations, *e.g.*, the direction and the duration of a movement, the resistance offered and the posture of the body or of its individual parts.

The foregoing classification of the efferent and afferent nerve-fibers has been established partly by experiment and partly by histologic investigations, *e.g.*

Stimulation of the ventral, efferent root fibers produces:

1. Tetanic contraction of skeletal muscles.
2. Discharge of secretions from glands.
3. Increase in the degree of the contraction, the tonus, of the muscle walls of the peripheral arteries.
4. Variations in the degree of the contraction, the tonus, of the muscle walls of certain viscera either in the way of augmentation or inhibition.[1]

Division of the ventral root fibers is followed by:

1. Relaxation of skeletal muscles and loss of movement.
2. Cessation in the discharge of secretions from glands.
3. Temporary dilatation and loss of the tonus of blood-vessels.
4. Temporary impairment of the normal activities of the visceral muscles from loss of central nerve control; the degree of impairment depending on the nature of the viscus involved.

Peripheral stimulation of the dorsal afferent root fibers produces:

1. Reflex excitation of spinal centers, in consequence of which there is an increased activity of skeletal muscles, glands, blood-vessels, and visceral walls.
2. Reflex inhibition of spinal nerve-centers, in consequence of which there may be a decrease in the activities of skeletal muscles, glands, blood-vessels, and viscera.
3. Sensations of touch, temperature, pressure, and pain.
4. Sensations of the duration and direction of muscle movements, of the resistance offered and of the position of the body or of its individual parts (muscle sensation).

Division of the dorsal root fibers is followed by:

1. Loss of the power of exciting or inhibiting reflexly the activities of spinal nerve-centers and in consequence a loss of the power of exciting or inhibiting the activities of peripheral organs.
2. Loss of sensation in all parts to which they are distributed.

[1]These last three phenomena are especially associated with the ventral roots of the second thoracic to the third or fourth lumbar nerves inclusive.

The ventral roots are, therefore, efferent in function, transmitting nerve impulses from the spinal cord to the peripheral organs which excite them to activity.

The dorsal roots are afferent in function, transmitting nerve impulses from the general periphery to (*a*) the spinal cord where they excite its contained nerve-centers to activity or to a more or less complete cessation of activity (inhibition), and (*b*) to the cerebrum where they excite its centers to activity with the development of sensations.

The peripheral terminations of the *efferent* nerves are, therefore, to be found in close histologic relation with skeletal-muscle and visceral-muscle fibers and with gland epithelium. The peculiar termination in each situation has been termed an "end organ." The afferent nerves are likewise in close histologic relation with the skin, mucous membrance and the sense organs. The afferent end organs are in some instances extremely complex, such as those found in the eye (retina), the internal ear, the nose and tongue.

The end organs of the afferent nerves are specialized, highly irritable structures placed between the nerve-fibers and the surface of the body. They are especially adapted for the reception of those external forces technically known as stimuli, and for the liberation of energy capable of exciting the nerve-fiber to activity.

Nerve Degeneration.—If any one of the cranial or spinal nerves be divided in any portion of its course, the part in connection with the periphery in a short time exhibits certain structural changes, to which the term degeneration is applied. The portion in connection with the brain or cord retains its normal condition. The degenerative process begins simultaneously throughout the entire course of the nerve, and consists in a disintegration and reduction of the medulla and axis cylinder into nuclei, drops of myelin, and fat, which in time disappear through absorption leaving the neurilemma intact. Coincident with these structural changes there is a progressive alteration and diminution in the excitability of the nerve. Inasmuch as the central portion of the nerve, which retains its connection with the nerve-cell, remains histologically normal, it has been assumed that the nerve-cells exert over the entire course of the nerve-fibers a nutritive or a trophic influence. This idea has been greatly strengthened since the discovery that the axis-cylinder, or the axon, has its origin in and is a direct outgrowth of the cell. When separated from the parent cell, the fiber appears to be incapable of itself of maintaining its nutrition.

The relation of the nerve-cells to the nerve-fibers, in reference to their nutrition, is demonstrated by the results which follow section of the ventral and dorsal roots of the spinal nerves. If the anterior root alone be divided, the degenerative process is confined to the peripheral portion, the central portion remaining normal. If the posterior root be divided on the peripheral side of the ganglion, degeneration takes place only in the peripheral portion of the nerve. If the root be divided between the ganglion and the cord, degeneration takes place only in the central portion of the root. From these facts it is evident that the trophic centers for the ventral and dorsal roots lie in the spinal cord and spinal nerve ganglia, respectively, or, in other words, in the cells of which they are an integra part. The structural changes which nerves undergo after separation from their centers are degenerative in character, and the process is usually spoken of, after its discoverer, as the *Wallerian degeneration.* When the degeneration of the efferent nerves is completed, the structures to which they are distributed, especially the muscles, undergo an atrophic or fatty degeneration, with a change or loss of their irritability. This is, apparently, not to be attributed merely to inactivity, but rather to a loss of nerve influences, inasmuch as inactivity merely leads to atrophy and not to degeneration.

Reactions of Degeneration.—In consequence of the degeneration and changes in irritability which occur in nerves when separated from their centers and in muscles when separated from their related nerves, either experimentally or as the result of disease, the response of these structures to the induced and the make-and-break of the constant currents differs from that observed in the physiologic condition. The facts observed under the application of these two forms of electricity are of the greatest importance in the diagnosis and therapeutics of the precedent lesions. The principal difference of behavior is observed in the muscles, which exhibit a diminished or abolished excitability to the induced current, while at the same time manifesting an increased excitability to the constant current; so much so is this the case that a closing contraction is just as likely to occur at the positive as at the negative pole. This peculiarity of the muscle response is termed the *reaction of degeneration.* The synchronous diminished excitability of the nerves is the same for either current. The term "partial reaction of degeneration" is used when there is a normal reaction of the nerves, with the degenerative reaction of the muscles. This condition is observed in progressive muscular atrophy.

PHYSIOLOGIC PROPERTIES OF NERVES

Nerve Irritability or Excitability and Conductivity.—These terms are employed to express that condition of a nerve which enables it to develop and to conduct nerve impulses from the center to the periphery, from the periphery to the center, in response to the action of stimuli. A nerve is said to be excitable or irritable as long as it possesses these capabilities or properties. For the manifestation of these properties the nerve must retain a state of physical and chemic integrity; it must undergo no change in structurc or chemic composition. The irritability of an *efferent* nerve is demonstrated by the contraction of a muscle, by the secretion of a gland. or by a change in the caliber of a blood-vessel, whenever a corresponding nerve is stimulated. The irritability of an *afferent* nerve is demonstrated by the production of a sensation or a reflex action when ever it is stimulated. The irritability of nerves continues for a certin period of time after separation from the nerve centers and even after the death of the animal, varying in different classes of animals. In the warm-blooded animals, in which the nutritive changes take place with great rapidity, the irritability soon disappears—a result due to disintegrative changes in the nerve caused by the withdrawal of the blood-supply. In cold-blooded animals. on the contrary, in which the nutritive changes take place relatively slowly, the irritability lasts, under favorable conditions, for a considerable time. Other tissues besides nerves possess irritability, that is, the property of responding to the action of stimuli—*e.g.*, glands and muscles, which respond by the production of a secretion or a contraction.

Independence of Tissue Irritability.—The irritability of nerves is distinct and independent of the irritability of muscles and glands, as shown by the fact that it persists in each a variable length of time after their histologic connections have been impaired or destroyed by the introduction of various chemic agents into the circulation. Curara, for example, induces a state of complete paralysis by modifying or depressing the conductivity of the end organs of the nerves just where they come in contact with the muscles without impairing the irritability of either nerve trunks or muscles. Atropin induces complete suspension of glandular activity by impairing the terminal organs of the secretor nerves just where they come into relation with the gland cells, without destroying the irritability of either gland or nerve.

Stimuli of Nerves.—Nerves do not possess the power of spontaneously generating and propagating nerve impulses; they can be aroused to activity only by the action of an extraneural stimulus. In the living condition the stimuli capable of throwing the nerve into an active condition act for the most part on either the central or peripheral end of the nerve. In the case of motor nerves the stimulus to the excitation, originating in some molecular disturbance in the nerve-cells, acts upon the nerve-fibers in connection with them. In the case of sensor or afferent nerves the stimuli act upon the peculiar end organs with which the sensor nerves are in connection, which in turn excite the nerve-fibers. Experimentally, it can be demonstrated that nerves can be excited by a sufficiently powerful stimulus applied in any part of their extent.

Nerves respond to stimulation according to their habitual function; thus, stimulation of a sensor nerve, if sufficiently strong, results in the sensation of pain; of the optic nerve, in the sensation of light; of a motor nerve, in contraction of the muscle to which it is distributed; of a secretor nerve, in the activity of the related gland, etc. It is, therefore, evident that peculiarity of nerve function depends neither upon any special construction or activity of the nerve itself, nor upon the nature of the stimulus, but entirely upon the peculiarities of its central and peripheral end organs.

Nerve stimuli may be divided into—

1. *General stimuli,* comprising those agents which are capable of exciting a nerve in any part of its course.

2. *Special stimuli,* comprising those agents which act upon nerves only through the intermediation of the end organs.

General stimuli:

1. Mechanical: as from a blow, pressure, tension, puncture, etc.

2. Thermal; heating a nerve at first increases and then decreases its excitability.

3. Chemic: sensor nerves respond somewhat less promptly than motor nerves to this form of irritation.

4. Electric: either the constant or interrupted current.

5. The normal physiologic stimulus:

(*a*) Centrifugal or efferent, if proceeding from the center toward the periphery.

(*b*) Centripetal or afferent, if in the reverse direction.

Special stimuli:

1. Light or ethereal vibrations acting upon the end organs of the optic nerve in the retina.

2. Sound or atmospheric undulations acting upon the end organs of the auditory nerve.

3. Heat or vibrations of the air upon the end organs in the skin.

4. Chemic agencies acting upon the end organs of the olfactory and gustatory nerves.

Nature of the Nerve Impulse.—As to the nature of the nerve impulse generated by any of the foregoing stimuli either general or special, but little is known. It has been supposed to partake of the nature of a molecular disturbance, a combination of physical and chemical processes attended by the liberation of energy, which propagates itself from molecule to molecule. Judging from the deflections of the galvanometer needle it is probable that when the nerve impulse makes its appearance at any given point it is at first feeble but soon reaches a maximum development after which it speedily declines and disappears. It may, therefore, be graphically represented as a wave-like movement with a definite length and time duration. Under strictly physiological conditions the nerve impulse passes in one direction only; in efferent nerves from the center to the periphery, in afferent nerves from the periphery to the center. Experimentally, however, it can be demonstrated that when a nerve impulse is aroused in the course of a nerve by an adequate stimulus it travels equally well in both directions from the point of stimulation. When once started the impulse is confined to the single fiber and does not diffuse itself to fibers adjacent to it in the same nerve trunk.

Rapidity of Transmission of Nerve Force.—The passage of a nervous impulse, either from the brain to the periphery or in the reverse direction, requires an appreciable period of time. The velocity with which the impulse travels in human sensor nerves has been estimated at about 190 feet a second, and for motor nerves at from 100 to 200 feet a second. The rate of movement is, however, somewhat modified by temperature, cold lessening and heat increasing the rapidity; it is also modified by electric conditions, by the action of drugs, the strength of the stimulus, etc. The rate of transmission through the spinal cord is considerably slower than in nerves, the average velocity for voluntary motor impulses being only 33 feet a second, for sensitive impressions 40 feet, and for tractile impressions 140 feet a second.

Electric Currents in Muscles and Nerves.—If a muscle or nerve be divided and non-polarizable electrodes be placed upon the natural longitudinal surface at the equator, and upon the transverse section, electric currents are observed with the aid of a delicate galvanometer. The direction of the current is always from the positive equatorial surface to the negative transverse surface. The strength of the current increases or diminishes according as the positive electrode is moved toward or from the equator. When the electrodes are placed on the two transverse ends of a nerve, an axial current will be observed the direction of which is opposite to that of the normal impulse of the nerve.

The *electromotive force* of the strongest nerve-current has been estimated to be equal to the 0.026 of a Daniell battery; the force of the current of the frog muscle, about 0.05 to 0.08 of a Daniell.

Negative Variation of Currents in Muscles and Nerves.—If a muscle or nerve be thrown into a condition of tetanus, it will be observed that the currents undergo a diminution of negative variation, a change which passes along the nerve in the form of a wave and with a velocity equal to the rate of transmission of the nerve impulse. The wave-length of a single negative variation has been estimated to be eighteen millimeters, the period of its duration being from 0.0005 to 0.0008 of a second.

It is asserted by Hermann that perfectly fresh, uninjured muscles and nerves are devoid of currents, and that the currents observed are the result of molecular death at the point of section, this point becoming negative to the equatorial point. He applies the term "action currents" to the currents obtained when a muscle is thrown into a state of activity.

Electrotonus.—The passage of a direct galvanic current through a portion of a nerve excites in the parts beyond the electrodes a condition of electric tension, or *electrotonus*, during which the *excitability* of the nerve is *decreased* near the anode or positive pole, and *increased* near the cathode or negative pole; the increase of excitability in the *catelectrotonic area*—that nearest the muscle—being manifested by a more marked contraction of the muscle than the normal when the nerve is irritated in this region. The passage of an *inverse* galvanic current excites the same condition of electrotonus; the *diminution* of excitability near the anode, the *anelectrotonic* —that now nearest the muscle—being manifested by a less marked contraction than the normal when the nerve is stimulated in this region. Similar conditions exist within the electrodes. Between the electrodes is a neutral point, where the catelectrotonic area merges into the anelectrotonic area. If the current be a strong one, the neutral point approaches the cathode; if weak, it approaches the anode.

When a nerve impulse passes along a nerve, the only appreciable effect is a change in its electric condition, there being no change in its temperature, chemic composition, or physical condition. The natural nerve-currents, which are always present in a living nerve as a result of its nutritive activity, in great part disappear during the passage of an impulse, undergoing a *negative variation.*

Law of Contraction.—If a *feeble* galvanic current be applied to a recent and excitable nerve, contraction is produced in the muscles only upon the *making* of the circuit with both the direct and inverse currents.

If the current be *moderate* in intensity, the contraction is produced in the muscle, both upon the *making* and *breaking* of the circuit, with both the direct and inverse currents.

If the current be *intense*, contraction is produced only when the circuit is *made* with the direct current, and only when it is *broken* with the inverse current.

Reflex Action.—Inasmuch as many of the muscle movements of the body, as well as the formation and discharge of secretions from glands, variations in the caliber of blood-vessels, inhibition and acceleration in the activity of various organs, are the result of stimulations of the terminal organs of afferent nerves, they are termed, for convenience, reflex actions, and, as they take place independently of the brain or of volitional impulses, they are also termed involuntary actions. As many of the processes to be described in succeeding chapters are of this character, requiring for their performance the coöperation of several organs and tissues associated through the intermediation of the nervous system, it seems advisable to consider briefly, in this connection, the parts involved in a reflex action, as well as their mode of action. As shown in figure 10, the necessary structures are as follows:

1. A receptive surface, skin, mucous membrane, sense organ, etc.
2. An afferent nerve.
3. An emissive cell, from which arises
4. An efferent nerve, distributed to a responsive organ, as,
5. Muscle, gland, blood-vessel, etc.

Such a combination of structures constitutes a reflex mechanism of arc the nerve portion of which is composed of but two neurons—an afferent and an efferent. An arc of this simplicity would of necessity subserve but a simple movement. The majority of reflex activities, however, are extremely complex, and involve the coöperation and coördination of a number of structures frequently situated at distances more or less remote from one another. This implies that a number of neurons are associated in function. The afferent neurons are brought into relation with the dendrites of the efferent neurons by the end tufts of the collateral branches, which may extend for some distance up and down the cord before passing into the various segments.

For the excitation of a reflex action it is essential that the stimulus applied to the sentient surface be of an intensity sufficient to develop in the terminals of the afferent nerve a series of nerve impulses, which, traveling inward, will be distributed to and received by the dendrites of the emissive or motor cell. With the reception of these impulses there is apparently a disturbance of the equilibrium of its molecules, a liberation of energy, and in consequence, a transmission outward of impulses through the efferent nerve to muscle, gland, or blood-vessel, separately or collectively, with the production of muscular contraction, glandular secretion, vascular dilatation or contraction, etc. The reflex actions take place, for the most part, through the spinal cord and medulla oblongata, which, in virtue of their contained centers, coördinate the various organs and tissues concerned in the performance of the organic functions. The movements of mastication; the secretion of saliva; the muscular, glandular, and vascular phenomena of gastric and intestinal digestion; the vascular and respiratory movements; the mechanism of micturition, etc., are illustrations of reflex activity.

FOODS AND DIETETICS

During the functional activity of every organ and tissue of the body the living material of which it is composed—the *protoplasm*—undergoes more or less disintegration. Through a series of descending chemic stages it is reduced to a number of simpler compounds, which are of no further value to the body, and which are in consequence eliminated by the various eliminating or excretory organs—the lungs, kidneys, skin, liver. Among these compounds the more important are carbon dioxid, urea, and uric acid. Many other compounds, inorganic as well as organic, are also eliminated in the water discharged from the body, in which they are held in solution. Coincident with this disintegration of the tissue there is an evolution or disengagement of energy, particularly in the form of heat.

In order that the tissues may regain their normal composition and thus be enabled to continue in the performance of their functions, they must be supplied with the same nutritive materials of which their protoplasm originally consisted—viz., water, inorganic salts, proteins, sugar, fat. These materials are furnished by the blood during its passage through the capillary blood-vessels. The blood is a reservoir of nutritive material in a condition to be absorbed, organized, and transformed into new living tissue.

Inasmuch as the loss of material from the body daily, which is very great, is compensated for under other forms by the blood, it is evident that this fluid would rapidly diminish in volume were it not restored by the introduction of new and corresponding materials. As soon as the blood volume falls to a certain point, the sensations of hunger and thirst arise, which in a short time lead to the necessity of taking food.

In addition to the direct appropriation of food by the tissues it is highly probable that an indefinite amount undergoes oxidation and disintegration without ever becoming an integral part of the tissues, and thus directly contributes to the production of heat.

Quantities of Food Materials Required Each Day.—The quantities of the different nutritive materials that are required each day for the growth and repair of the tissues and for the evolution of heat have been variously estimated by different observers. The following table shows the average diet scale of Vierordt and the amounts of the waste products to which it would give rise:

COMPARISON OF THE INCOME AND OUTCOME

Income		Outcome		
Protein	120 grams.	Water		3,114.00
Fat	90 grams.	Urinary solids	Urea	33.80
Starch	330 grams.	Urinary solids	Salts	26.00
Inorganic salts	32 grams.	Urinary solids	Extractives	6.00
Water	2,818 grams.	Feces		44.00
Oxygen	744 grams.	Carbon dioxid		910.00
Total	4,134 grams.			4,134.00

It will be observed that in the results of the foregoing experiment, the amount of water under outcome, exceeds the amount under income, by 296 grams. This water results from the union of a portion of the oxygen absorbed with the surplus hydrogen of the fats. If the diet consisted merely of protein and starch the two volumes of water would practically balance each other.

Many other attempts have been made to construct a suitable diet for a man weighing 70 kilos while doing light or moderate work. The following are accepted estimates:

	Ranke, grams	Voit, grams	Moleschott, grams	Atwater, grams
Protein	100	118	130	125
Fat	100	56	84	125
Starch	250	500	550	400

The Energy of the Animal Body.—The food consumed daily not only repairs the loss of material from the body, but also furnishes the energy to replace that which is expended daily in the shape of heat of motion. All the energy of the body can be traced to the chemic changes going on in the tissues, and more particularly to those changes involved in the oxidation of the foods.

The amount of heat yielded by any given food principle can be determined by burning it to carbon dioxid and water, and ascertaining the extent to which it will, when so liberated, raise the temperature of a given volume of water. This amount of heat may be expressed in Calories. A Calorie is the amount of heat required to raise the temperature of *one kilogram* of water *one degree* Centigrade.

The following estimates give, approximately, the number of Calories produced when the food is reduced within the body to urea, carbon dioxid, and water:

1 gram of protein yields	4.124 kilogram Calories.
1 gram of fat yields	9.353 kilogram Calories.
1 gram of starch yields	4.116 kilogram Calories.

The total number of kilogram Calories yielded by any given diet scale can be readily determined by multiplying the preceding factors by the quantities of material consumed. The diet scale of Ranke, for example, yields the following amount:

100 grams of protein yield	412.4 Calories.
100 grams of fat yield	935.3 Calories.
240 grams of starch yield	987.8 Calories.
Total	2,335.5 Calories.

It has also been determined experimentally that one gram of protein, one gram of fat, and one gram of starch, when completely oxidized, will yield energy sufficient to perform, 1,850, 3,841 and 1,567 kilogrammeters of work, respectively. A kilogrammeter of work is one kilogram raised one meter high.

The total energy of the Ranke diet scale can be easily calculated—*e.g.*,

100 grams of protein yield	185,000 kilogrammeters.
100 grams of fat yield	384,100 kilogrammeters.
240 grams of starch yield	397,680 kilogrammeters.
Total	966,780 kilogrammeters.

It will be thus seen that the food consumed daily yields 2,335 *kilogram Calories*, which can be translated into its mechanical equivalent 966,780 kilogrammeters of work.

CLASSIFICATON OF FOOD PRINCIPLES

1. **Proteins.**

Principle	Where found
Myosin	Flesh of animals.
Vitellin, albumin	Yolk of egg, white of egg.
Fibrin, globulin	Blood contained in meat.
Caseinogen	Milk, cheese.
Gliadin and glutinin	Grain of wheat and other cereals.
Vegetable albumin	Soft, growing vegetables.
Legumin	Peas, beans, lentils, etc.

2. **Fats.**

Animal fats and oils *Stearin, olein* *Palmitin, fat acids*	Found in the adipose tissue of animals, seeds, grains, nuts, fruits and other vegetable tissues.

3. **Carbohydrates.**

Saccharose, or cane-sugar	Sugar-cane.
Dextrose, or glucose *Levulose,* or *fruit-sugar*	Fruits.
Lactose, or *milk-sugar*	Milk.
Maltose	Malt, malt foods.
Starch	Cereals, tuberous roots, and leguminous plants
Glycogen	Liver, muscles.

4. **Inorganic Principles.**—Water; sodium and potassium chlorids; sodium calcium, magnesium, and potassium phosphates; calcium carbonate; and iron.

5. **Vegetable Acids.**—Malic, citric, tartaric, and other acids, found principally in fruits.

6. **Accessory Foods.**—Tea, coffee, alcohol, cocoa, etc.

DISPOSITION OF FOOD

The Proteins.—The protein principles of the food while in the alimentary canal undergo a series of disintegrative changes by virtue of which they are reduced in part to simple nitrogen-holding bodies, monoamino- and diamino-acids and ammonia, and in part to their immediate antecedents peptids and polypeptids, after which they are absorbed from the intestinal contents. Recently evidence has been adduced which makes it probable that the amino-acids undergo no change in the act of absorption but enter the blood as such and are carried direct to the tissues. On reaching any given tissue the cells absorb and synthesize, perhaps under the influence of an enzyme, such amino-acids as they may need for their growth and repair. The surplus amino-acids, *i.e.*, those not utilized in the synthesis of tissue protein, may be synthesized to plasma-albumin, or stored unchanged or be deaminized, *i.e.*, separated perhaps by the action of an enzyme, into the amino-group, NH_2, and some carbonaceous radical. The amino-group is then combined with hydrogen, and subsequently with carbon dioxid, to form ammonium carbonate which is then transformed into urea, a transformation that takes place to some extent in the muscles (Folin); the carbonaceous remainder may be transformed into fat or sugar, which is subsequently oxidized thus contributing to the production of heat. In the process of tissue metabolism the protein molecule undergoes disintegration and gives rise to amino-acids, the different elements of which may undergo changes similar to those just stated. The ammonia absorbed from the intestine is changed to ammonium carbonate carried direct to the liver and transformed into urea.

The Fats.—The fat principles while in the alimentary canal also undergo a series of changes whereby they are reduced by enzymic action to soap and glycerin, under which forms they are absorbed. During the act of absorption the soap and glycerin are synthesized to human fat. The fine particles thus formed in the intestinal wall are carried by the lymph vessels to the thoracic duct, and thence into the blood stream, from which they rapidly disappear. Though it is possible that a portion of the fat enters directly into the formation of the living material in general, it is generally believed that it is at once oxidized and reduced to carbon dioxid and water with the liberation of energy. The natural supposition that a portion of the synthesized fat is directly stored up in the cells of the areolar connective tissue, thus giving rise to adipose tissue, has been a subject of much controversy, though modern experimentation renders this very probable. The body-fat, under physiologic conditions, is mainly, however, a product of the transformation of carbohydrates.

The Carbohydrates.—Carbohydrate principles are reduced during digestion to simple forms of sugar, chiefly dextrose and levulose. Under these forms they are absorbed into the blood. These compounds are then carried to the liver and to the muscles where they are dehydrated and stored under the form of starch, termed animal starch or glycogen. Subsequently glycogen is transformed by hydration to sugar, after which it is oxidized to carbon dioxid and water. The intermediate stages through which sugar passes before it is reduced to carbon dioxid and water are only imperfectly known. Though a large part of the carbohydrate material is at once oxidized, it is now well established that another portion contributes to the formation of, if it is not directly converted into, fat. As the carbohydrates form a large portion of the food, they contribute materially to the liberation of energy.

The Inorganic Principles.—The inorganic principles, though apparently not playing as active a part in the metabolism of the body as the organic, are nevertheless essential to its physiologic activity.

Water is present in all the fluids and solids of the body. It promotes the absorption of new material from the alimentary canal; it holds the various ingredients of the blood, lymph, and other fluids in solution; it hastens the absorption of waste products from the tissues, and promotes their speedy elimination from the body.

Sodium chlorid is present in all parts of the body to the extent of 110 gm. The average amount eliminated daily is 15 gm. Its necessity as an article of diet is at once apparent. Taken as a condiment, it imparts sapidity to the food, excites the flow of the digestive fluids, influences the passage of nutritive material through animal membranes, and furnishes the chlorin for the free hydrochloric acid of the gastric juice. In some unknown way it favorably promotes the activity of the general nutritive process.

The *potassium salts* are also essential to the normal activity of the nutritive process. When deprived of these salts, animals beome weak and emaciated. When given in small doses, they increase the force of the heart-beat, raise the arterial pressure, and thus increase the action of the circulation of the blood.

The *calcium phosphate and carbonate* are utilized in imparting solidity to the tissues, more especially the bones and teeth. Many articles of food contain these salts in quantities sufficient to restore the amount lost daily.

The *vegetable acids* increase the secretions of the alimentary canal, and are apt, in large amounts, to produce flatulence and diarrhea. After entering into combination with bases to form salts, they stimulate the action of the kidneys and promote a greater elimination of all the urinary constituents. In some unknown way they influence nutrition; when deprived of these acids, the individual becomes scorbutic.

The *accessory foods*, coffee and tea, when taken in moderation, overcome the sense of fatigue and mental unrest consequent on excessive physical and mental exertion. Coffee increases the action of the intestinal glands and acts as a laxative. After absorption, its active principle, *caffein* stimulates the action of the heart, raises the arterial pressure, and excites the action of the brain. Tea acts as an astringent, owing to the tannic acid it contains. One effect of the tannic acid is to coagulate the digestive ferments and to interfere with the activity of the digestive process.

Alcohol when taken in small quantities stimulates the digestive glands to increased activity and thus promotes digestive power. Its absorption into the blood is followed by increased action of the heart, dilatation of the cutaneous blood-vessels, a sensation of warmth, and an excitation of the brain. In large quantities it acts as a paralyzant, depressing more especially the vaso-constrictor nerve-centers and certain areas of the brain, as shown by an impairment in the power of sustained attention, clearness of judgment, and muscle coördination.

Alcohol is undoubtedly oxidized in the body, as only about 2 per cent. can be obtained from the urine and expired air. It thus contributes to the store of the body-energy. Whether for this reason it can be regarded as a food—that is, whether it can be substituted in part at least for fat or carbohydrate material without impairing the protein metabolism—is at present a subject of experimentation and discussion. According to some investigators, alcohol does not retard protein metabolism, for when it is introduced into the body in amounts equivalent to the carbohydrates withdrawn from the food there is at once a rise in the amount of nitrogen excreted. Hence it cannot be regarded as a food. According to other investigators, alcohol retards or protects protein metabolism just as effectually as an equivalent amount of starch or sugar. Many more experiments are required to decide this question. When taken habitually in large quantities, alcohol deranges the activities of the digestive organs, lowers the body temperature, impairs muscle power, lessens the resistance to depressing external conditions, diminishes the capacity for sustained mental work, and leads to the development of structural changes in the connective tissues of the brain, spinal cord, and other organs. In infectious diseases and in cases of depression of the vital powers it is most use ful as a restorative agent.

Inanition or Starvation.—If these nutritive principles be not supplied in sufficient quantity, or if they are withheld entirely, a condition of physiologic decay is established, to which the term inanition or starvation is applied. The phenomena which characterize this pathologic process are as follows—viz., hunger, intense thirst, gastric and intestinal uneasiness and pain, muscle weakness and emaciation, a diminution in the quantity of carbon dioxid exhaled, a lessening in the amount of urine and its constituents excreted, a diminution in the volume of the blood, an exhalation of a fetid odor from the body, vertigo, stupor, delirium, and at times convulsions, a fall of bodily temperature, and, finally, death from exhaustion.

During starvation the loss of different tissues, before death occurs, averages 4/10, or 40 per cent., of their weight.

Those tissues which lose *more* than 40 *per cent.* are: Fat, 93.3; blood, 75; spleen, 71.4; pancreas, 64.1; liver, 52; heart, 44.8; intestines, 42.4; muscle, 42.3. Those which lose *less* than 40 *per cent.* are: The muscular coat of the stomach, 39.7; pharynx and esophagus, 34.2; skin, 33.3; kidneys, 31.9; respiratory apparatus, 22.2; bones, 16.7; eyes, 10; nervous system, 1.9

The *fat* entirely disappears, with the exception of a small quantity which remains in the posterior portion of the orbits and around the kidneys. The *blood* diminishes in volume and loses its nutritive properties. The *muscles* undergo a marked diminution in volume and become soit and flabby. The *nervous system* is last to suffer, not more than two per cent., disappearing before death occurs.

The *appearances* presented by the body after death from starvation are those of anemia and great emaciation; almost total absence of fat; bloodlessness; a diminution in the volume of the organs; an empty condition of the stomach and bowels, the coats of which are thin and transparent. There is a marked disposition of the body to undergo decomposition, giving rise to a very fetid odor.

The *duration of life* after a complete deprivation of food varies from eight to thirteen days, though life can be maintained much longer if a quantity of water be obtained. The water is more essential under these circumstances than the solid matters, which can be supplied by the organism itself.

COMPOSITION OF FOODS

The food principles essential to the maintenance of the nutrition of the body are contained in varying proportions in compound substances termed foods; *e.g.*, meat, milk, wheat, potatoes, etc. Their nutritive value depends partly on the amounts of their contained food principles and partly on their digestibility. The dietary of civilized man embraces foods derived from both the animal and vegetable worlds.

The following tables show the percentage composition of the edible portions of foods as well as the amount of heat liberated per pound when oxidized in the body, according to Atwater and Bryant.

Composition of Animal Foods.—The following table shows the average percentage composition of various kinds of meats, cow's milk, and eggs:

Kind of food materials	Water	Unavailable nutrients	Proteins	Fat	Carbohydrates	Ash	Fuel value per lb., 453.6 grams
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Calories
Beef:							
Loin, lean.......	67.0	1.2	19.1	12.1	......	1.0	900
Loin, fat........	54.7	1.9	17.0	26.2	......	0.9	1,470
Round, lean.....	70.0	1.0	20.7	7.5	......	1.1	735
Round, fat......	60.4	1.6	18.9	18.5	......	1.0	1,175
Veal:							
Cutlets (round) .	70.7	1.3	19.7	7.3	......	0.8	710
Liver...........	73.0	0.9	9.7	5.0	......	1.0	410
Mutton:							
Leg............	62.8	1.7	17.9	17.1	......	0.8	1,095
Loin	50.2	2.4	15.5	31.4	......	0.6	1,660
Pork:							
Loin chops	52.0	2.2	16.1	28.6	......	0.8	1,555
Ham...........	53.9	2.1	14.8	27.5	......	0.6	1,480
Fowl:	63.7	1.6	18.7	15.5	......	0.8	1,040
Turkey.........	55.5	1.9	20.5	21.8	......	0.8	853
Mackerel.........	73.4	1.3	18.1	6.7	......	0.9	650
Halibut	75.4	1.1	18.0	4.9	......	0.8	570
Milk.............	87.0	0.5	3.2	3.8	5.0	0.5	310
Eggs, boiled.......	73.2	1.2	12.8	11.4	......	0.6	755

Composition of Cereal Foods.—The average composition of the principal cereals is shown in the following table:

Kind of food material	Water	Unavailable nutrients	Proteins	Fat	Carbohydrates	Ash	Fuel value per lb., 453.6 grams
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Calories
Entire wheat flour.	11.4	4.5	10.7	1.7	70.9	0.8	1,645
Rye flour.........	12.9	3.6	5.3	0.8	76.9	0.5	1,610
Rice	12.3	3.7	6.5	0.3	76.9	0.3	1,610
Barley, pearled....	11.5	4.0	6.6	1.0	76.10	0.8	1,630
Buckwheat flour...	13.6	3.5	5.2	1.1	75.9	0.7	1,600
Corn meal........	12.5	4.0	7.5	1.7	73.5	0.8	1,625
Oat meal	7.8	5.6	13.4	6.6	65.2	1.4	1,795
Whole wheat bread	38.4	3.2	7.5	0.8	49.1	1.0	1,125
White bread	35.3	3.3	7.1	1.2	52.3	0.8	1,195
Graham crackers .	5.4	4.8	7.7	8.5	72.5	1.1	1,900

Composition of Vegetable Foods.—The average composition of some of the principal vegetables is shown in the following table:

Kind of food material	Water	Unavailable nutrients	Proteins	Fat	Carbohydrates	Ash	Fuel value per lb., 453.6 grams
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Calories
Beans, lima, dried	10.4	6.7	12.8	1.4	65.6	3.1	1,565
Beans, lima, green	68.5	2.7	5.3	0.6	21.6	1.3	525
Beans, white, dried	12.6	7.5	15.8	1.6	59.9	2.6	1,530
Beans, string, cooked[1]	95.3	0.5	0.6	1.0	1.9	0.7	90
Peas, dried	9.5	7.6	17.3	0.9	62.5	2.2	1,508
Peas, green, cooked[1]	73.8	2.5	5.1	3.1	14.4	1.1	490
Potatoes, boiled, cooked[1]	75.5	1.7	1.9	0.1	20.0	0.8	415
Potatoes, sweet	51.9	3.0	2.2	1.9	40.3	0.7	885
Beets, cooked[1]	88.6	1.2	1.7	0.1	7.2	1.2	170
Cabbage	91.5	0.7	1.2	0.3	5.5	0.8	140
Tomatoes	94.3	0.4	0.7	0.4	3.8	0.4	100
Turnips	89.6	0.8	1.0	0.2	7.8	0.6	175
Egg-plant	92.9	0.6	0.9	0.3	4.9	0.4	120
Spinach, fresh	92.3	1.0	1.6	0.3	3.2	1.6	100
Asparagus, cooked	91.6	1.0	1.7	3.0	2.1	0.6	195

[1]With butter, etc., added.

DIGESTION

Digestion is a physical and chemic process by which the food introduced into the alimentary canal is liquefied and its nutritive principles transformed by the digestive fluids into new substances capable of being absorbed into the blood.

The **digestive apparatus** consists of the alimentary canal and its appendages—viz., teeth, lips and tongue; the salivary, gastric and intestinal glands; the liver and pancreas.

Digestion may be divided into several stages; prehension, mouth digestion (mastication and insalivation), deglutition, gastric and intestinal digestion, and defecation.

Prehension, the act of conveying food into the mouth, is accomplished by the hands, lips, and teeth.

Mouth Digestion.—Mastication is the mechanical division of the food, and is accomplished by the teeth and the movements of the lower jaw under the influence of muscular contraction. When throughly divided, the food presents a larger surface for the solvent action of the digestive fluids, thus enabling them to exert their respective action more effectively and in a shorter period of time.

The **teeth** are thirty-two in number, sixteen in each jaw, and divided into four incisors or cutting teeth, two canines, four bicuspids, and six molars or grinding teeth; each tooth consists of a crown covered by enamel, a neck, and a root surrounded by the crusta petrosa and embedded in the alveolar process; a section through a tooth shows that its substance is made of *dentine*, in the center of which is the pulp cavity containing blood-vessels and nerves.

The *lower jaw* is capable of making a downward and an upward, a lateral and an anteroposterior movement, dependent upon the construction of the temporomaxillary articulation.

The jaw is *depressed* by the contraction of the *digastric*, *geniohyoid*, *mylohyoid*, and *platysma myoides* muscles; *elevated* by the *temporal*, *masseter*, and *internal pterygoid* muscles; moved *laterally* by the alternate contraction of the *external pterygoid* muscles; moved *anteriorly* by the *pterygoid*, and *posteriorly* by the united actions of the *geniohyoid*, *mylohyoid*, and posterior fibers of the *temporal* muscles.

The food is kept between the teeth by the *intrinsic* and *extrinsic* muscles of the tongue from within, and the *orbicularis oris* and *buccinator* muscles from without.

The **movements of mastication,** though originating in an effort of the will and under its control, are, for the most part, of an automatic or reflex character, taking place through the medulla oblongata and induced by the presence of food within the mouth. The nerves and nerve-centers involved in this mechanism are shown in the following table:

Nerve Mechanism of Mastication

Afferent nerves	Efferent nerves
1. Lingual branches of the trigeminal nerve.	1. Small root of the trigeminal nerve.
2. Glossopharyngeal.	2. Hypoglossal.
	3. Facial.

The impressions made upon the terminal filaments of the afferent nerves are transmitted to the medulla; motor impulses are here generated which are transmitted through the efferent nerves to the muscles involved in the movements of the lower jaw. The medulla not only generates motor impulses, but coördinates them in such a manner that the movements of mastication may be directed toward the accomplishment of a definite purpose.

Insalivation.—Insalivation is the incorporation of the food with the saliva secreted by the *parotid*, *submaxillary*, and *sublingual glands;* the *parotid* saliva, thin and watery, is poured into the mouth through Steno's duct; the *submaxillary* and *sublingual* salivas, thick and viscid, are poured into the mouth through Wharton's and Bartholin's ducts respectively.

In their minute structure the salivary glands resemble one another. They belong to the racemose variety, and consist of small sacs or vesicles, which are the terminal expansions of the smallest salivary ducts. Each vesicle or *acinus* consists of a basement membrane surrounded by blood-vessels and lined with epithelial cells. In the parotid gland the lining cells are granular and nucleated; in the submaxillary and sublingual glands the cells are large, clear, and contain a quantity of mucigen. During and after secretion very remarkable changes take place in the cells lining the acini, which are in some way connected with the essential constituents of the salivary fluids.

In the living serous glands—*e.g.*, parotid—during rest, the secretory cells lining the acini of the gland are seen to be filled with fine granules, which are often so abundant as to obscure the nucleus and enlarge the cells until the lumen of the acinus is almost obliterated. When the gland begins to secrete the saliva, the granules disappear from the outer boundary of the cells, which then become clear and distinct. At the end of the secretory activity the cells have been freed of granules and have become smaller and more distinct in outline. It would seem that the granular matter is formed in the cells during the period of rest and discharged into the ducts during the activity of the gland.

In the mucous glands—*e.g.*, submaxillary and sublingual—the changes that occur in the cells are somewhat different. During the intervals of digestion the cells lining the gland are large, clear, and highly refractive, and contain a large quantity of mucigin. After secretion has taken place the cells exhibit a marked change. The mucigin cells have disappeared, and in their place are cells which are small, dark, and composed of protoplasm. It would appear that the cells, during rest, elaborate the mucigin, which is discharged into the tubules during secretory activity, to become part of the secretion.

Mouth Saliva.—The saliva found in the mouth is an opalescent, slightly viscid, alkaline fluid, having a specific gravity of 1.005. Microscopic examination reveals the presence of salivary corpuscles and epithelial cells. Chemically it is composed of water protein materials and inorganic salts. The amount secreted daily has been estimated at about 2 lb.

Physiologic Action.—Experiments have shown that saliva has a two-fold action, viz., physical and chemical.

1. Physically saliva moistens and softens the food, unites its particles into a consistent mass and thus facilitates swallowing.

2. Chemically it converts boiled starch into sugar. It has a feeble if any action on raw starch by reason of the structure of the starch granule. Each granule consists of two portions, an envelope of cellulose and a contained material *granulose*, the true starch material. When subjected to the action of boiling water the granule swells and bursts forming a more or less viscid fluid, starch paste. If saliva be now added to this paste and kept at a temperature of about 100°F. for a few minutes, the paste becomes clear and liquid. The first stage in the digestion of starch is now complete with the formation of soluble starch. If the action of saliva be continued, substances intermediate between starch and sugar are formed to which the name dextrin has been given, *e.g.*,

$$\text{Starch} = \text{Soluble starch} = \left\{ \begin{array}{l} \text{Erythrodextrin} = \left\{ \begin{array}{l} \text{Achroödextrin} \\ \text{Maltose.} \end{array} \right. \\ \text{Maltose} \end{array} \right.$$

The erythrodextrin is so called because it gives rise to a red color with iodin. Achroödextrin is so called because it yields no color with iodin.

The sugar formed by the action of saliva is the compound sugar maltose the formula for which is $C_{12}H_{22}O_{11}$. This chemical action of saliva depends on the presence of an unorganized ferment or enzyme known as *ptyalin*.

Nerve Mechanism for the Secretion of Saliva.—The afferent and efferent nerves that constitute the nerve mechanism for the secretion of saliva are shown in the following tabulation:—

Afferent nerves	Nerve center	Efferent nerves
1. Lingual branches of the trigeminal nerve.	Medulla oblongata.	1. Auriculotemporal branch of the trigeminal nerve, for parotid gland.
2. Taste fibers in the glosso-pharyngeal.		2. Chorda tympani, for submaxillary and sublingual glands.
3. Taste fibers in the chorda tympani.		3. Sympathetic for all the glands.

The nerve centers exciting, through efferent nerves the secretion of saliva are located in the medulla oblongata and may be aroused to action (1) by nerve impulses descending from the brain in consequence of *psychic states* induced by the sight and odor of food and (2) by nerve impulses reflected through afferent nerves from the mouth developed by the taste of food. The afferent nerves thus stimulated in the second instance are those stated in the foregoing tabulation.

That the efferent nerves in the same tabulation are active in the production of the secretion is shown by the following facts:

Stimulation of the auriculotemporal branch increases the flow of saliva from the parotid gland; *division* arrests it.

Stimulation of the chorda tympani is followed by a dilatation of the blood-vessels of the submaxillary and sublingual glands, an increased flow of blood and an abundant discharge of saliva; *division* of the nerve arrests the secretion.

Stimulation of the cervical sympathetic is followed by a contraction of the blood-vessels, a diminished flow of blood, and a diminution of the secretion, which now becomes thick and viscid; *division* of the sympathetic is not, however, followed by complete dilatation of the vessels. There is evidence of the existence of a local vasomotor mechanism, which is *inhibited* by the chorda tympani.

Deglutition.—Deglutition is the act of transferring food from the mouth into the stomach, and may be divided into *three* stages:

1. The passage of the bolus from the mouth into the pharynx.
2. From the pharynx into the esophagus.
3. From the esophagus into the stomach.

In the *first stage*, which is entirely voluntary, the mouth is closed and respiration momentarily suspended; the tongue, placed against the roof of the mouth, arches upward and backward, and forces the bolus into the fauces.

The second and third stages, or the passage of the food through the pharynx and esophagus into the stomach, have been attributed until quite recently entirely to peristaltic movements of their musculature.

Recent experiments have demonstrated that deglutition consists of two phases: (1) a rapid rise of pressure in the pharynx, as a result of which liquid or semi-liquid foods are suddenly shot down to the lower end of the esophagus; (2) a peristaltic contraction of the musculature of the canal, which, acting as a supplementary force, carries onward any particles of food in the canal and forces the bolus through the closed *sphincter cardiæ* at the end of the esophagus.

The immediate cause of the sudden rise of pressure was shown to be the contraction of the mylohyoid muscles. When the nerves going to these muscles were divided in a dog, deglutition was practically abolished. These muscles are probably assisted in their action by the contraction of the hyoglossus muscles as well as the tongue itself.

The time required for a mouthful of liquid food to pass to the lower end of the esophagus is approximately about 0.1 second. If the cardiac orifice is normally closed, a period of about 6 or 7 seconds may elapse before the oncoming peristaltic wave reaches the lower end of the esophagus and forces the fluid into the stomach. If, however, a series of deglutitory acts follow one another in quick succession there is an inhibition of the cardiac sphincter and the peristaltic wave, until after the last swallow. The time required for the food to pass into the stomach varies in different animals and in different human beings.

The Closure of the Posterior Nares and Larynx.—Because of the rapid rise of pressure in the pharynx and esophagus during the act of swallowing the posterior nares and the opening of the larynx must be closed to prevent the food from entering them.

The posterior nares are closed against the entrance of the food by a septum formed by the pendulous veil of the palate and the posterior half arches. The palate is drawn upward and backward by the *levator palati* muscles, until it meets the posterior wall of the pharynx, which at this moment advances. At the same time it is made tense, by the action of the *tensor palati* muscles. This septum is completed by the advance toward the middle line of the posterior half arches caused by the contraction of the muscles, the *palato-pharyngei*, which compose them. When these structures are impaired in their functional activity, as in diphtheritic paralysis and ulcerations, there is not infrequently a regurgitation of food, especially liquids, into the nose.

The larynx is equally protected against the entrance of food during deglutition under normal circumstances. That this accident occasionally happens, giving rise to severe spasmodic coughing, and even in extreme cases to suffocation, is abundantly shown by the records of clinical medicine. Usually it does not occur, for the following reasons: just preceding and during the act of deglutition there is a complete suspension of the act of inspiration, by which particles of food might otherwise be drawn into the larynx; at the same time the larynx is always drawn well up under the base of the tongue and its entrance closed by the downward and backward movement of the epiglottis.

In addition to the downward and backward movement of the epiglottis and the ascent of the larynx under the base of the tongue, it is also probable that the larynx is protected from the entrance of food, in the rabbit at least, by the closure of the glottis itself.

GASTRIC DIGESTION

The Stomach.—Immediately beyond the termination of the esophagus the alimentary canal expands and forms a receptacle for the temporary retention of the food. To this dilatation the term stomach has been applied. This organ is somewhat pyriform in outline, and occupies the upper part of the abdominal cavity. It is about 25 to 35 centimeters long, 15 centimeters deep, and 10 to 12 centimeters wide, and has a capacity of about 1500 c.c. It presents two orifices, the cardiac or esophageal, and the pyloric; two curvatures, the lesser and the greater.

The general body of the stomach has been divided into two portions, viz., a large portion to the left, known as the *cardiac* portion and a small portion to right known as the *pyloric* portion. The extreme left end of the stomach is somewhat enlarged and forms the fundus.

The stomach walls are formed by three coats:

1. The serous, a reflection of the peritoneum.
2. The muscular, the fibers of which are arranged in a longitudinal, a circular, and an oblique direction. In the pyloric portion of the stomach the circular fibers increase enormously in number and form thick, well-defined rings termed the pyloric muscles. At the pyloric orifice the muscle fibers form a distinct band termed the *sphincter pylori.* The orifice between the lower end of the esophagus and stomach is also closed by a sphincter known as the *sphincter cardiæ.*
3. The mucous, which is somewhat larger than the muscular coat, and in consequence is thrown into folds or rugæ. The surface of the mucous coat is covered by tall, narrow, columnar epithelium.

Gastric Glands.—Embedded within the mucous membrane are to be found enormous numbers of tubular glands, which though resembling one another in general form, differ in their histologic details in various portions of the stomach.

In the cardiac end or fundus, the glands consist of several long tubules opening into a short, common duct, which opens by a wide mouth on the surface of the mucous membrane. Each gland consists primarily of a basement membrane lined by epithelial cells. In the duct the epithelium is of the columnar variety, resembling that covering the surface of the mucous membrane. The secretory portion of the tubule is lined by a layer of short, polyhedral, granular, and nucleated cells, which, as they border the lumen of the tubule, and thus occupy the central portion of the gland, are termed *central* cells. At irregular intervals, between the central cells and the wall of the tubule, are found large oval, reticulated cells, which, on account of their position, are termed *parietal* cells. (See Fig. 7.)

Each parietal cell is in relation with a system of fine canals, which open directly into the lumen of the gland. It is estimated that the fundus

FIG. 7.—Diagram showing the relation of the ultimate twigs of the blood-vessels, V and A and of the absorbent radicles to the glands of the stomach and the different kinds of epithelium—viz., above cylindric cells; small, pale cells in the lumen, outside which are the dark ovoid cells.—(*Yeo.*)

contains about five million glands. In the pyloric end of the stomach the glands are generally branched at their lower extremities, and the common duct is long and wide. The duct is lined by columnar epithelium, while the secreting part is lined by short, slightly columnar, granular cells. The parietal cells are entirely wanting. The epithelium covering the surface of the mucous membrane is tall, narrow and cylindric in shape, and consists of mucus-secreting goblet cells. The outer half of the cell contains a substance, mucinogen, which produces mucin. The gastric glands in both situations are surrounded by a fine connective tissue, which supports blood-vessels, nerves, and lymphatics.

Changes in the Cells during Secretion.—During the periods of rest and secretory activity the cells of the glands undergo changes in structure which are supposed to be connected with the production of the pepsin and hydrochloric acid. During rest, the protoplasm of the central cells becomes filled with granular matter; during the time of secretion this disappears, presumably passing into the lumen of the tubule, and as a result the protoplasm becomes clear and hyalin in appearance. The granular material is probably the mother substance, *pepsinogen*, which, inactive in itself, yields the active ferment, pepsin. The parietal cells during digestion increase in size, but do not become granular. It is at this period that they secrete the hydrochloric acid. After digestion they rapidly diminish in size and return to their former condition. The pyloric glands secrete pepsin only.

Gastric Juice.—The gastric juice obtained from the human stomach free from mucus and other impurities is a clear, colorless fluid with a constant acid reaction, a slightly saline and acid taste, and a specific gravity varying from 1.002 to 1.005. When kept from atmospheric influences, it resists putrefactive change for a long period of time, undergoes no apparent change in composition, and loses none of its digestive power. It will also prevent and even arrest putrefactive change in organic matter. The chemic composition of the gastric juice has never been satisfactorily determined, owing to the fact that the secretion as obtained from fistulous openings has not been absolutely normal. It may however be said to consist of water, organic matter, hydrochloric acid and various inorganic salts. The quantitative composition of the juice varies somewhat in different animals.

The organic matter present in gastric juice is a mixture of mucin and a protein, products of the metabolic activity of the epithelial cells on the surface of the mucous membrane and of the chief or central cells of the gastric glands respectively. Associated with the protein material are two possibly three ferment or enzyme bodies, termed pepsin, rennin and lipase. As is the case with other enzymes, their true chemic nature is practically unknown.

Pepsin.—Pepsin, though present in gastric juice, is not present as such in the chief cells of the glands, but is derived from a zymogen, propepsin or pepsinogen, when the latter is treated with hydrochloric acid. This antecedent compound is related to the granules observed in and produced by the cell protoplasm during the period of rest. Though pepsin is largely produced by the central cells of the cardiac glands, it is also produced, though in less amount, by the cells of the pyloric glands. Pepsin is the chief proteolytic or proteoclastic agent of the gastric juice and exerts its influence most energetically in the presence of hydrochloric acid and at a temperature of about 40°C.

Rennin.—Rennin or pexin is present in the gastric juice not only of man and all of the mammalia, but also of birds and even fish. In its origin from a zymogen substance; in its relation to an acid medium and an optimum temperature it bears a close resemblance to pepsin. Its specific action is the coagulation of milk, a condition due to a transformation of soluble caseinogen into a solid flaky body, casein.

Lipase.—Lipase, an enzyme found in pancreatic juice, has also been shown to be present in gastric juice, the specific function of which appears to be the digestion of hydrolysis of finely emulsified fat such as is found in milk.

Hydrochloric Acid.—Hydrochloric acid is the agent which gives to the gastric juice its normal acidity. Though the juice frequently contains lactic, acetic, and even phosphoric acids, it is generally believed that they are the result of fermentation changes occurring in the food, the result of bacterial action. The percentage of hydrochloric acid has been the subject of much discussion. The most recent investigations show that the initial acidity of the freshly secreted human gastric juice is between 0.32 and 0.48 per cent. HCl. This initial acidity is reduced by combination with food, admixture with saliva and gastric mucus, and by regurgitation of alkaline duodenal contents, to 0.15 or 0.2 per cent. HCl, the optimum acidity for the proteolytic activity of pepsin. As observed clinically, following various test meals, the acidity of the gastric contents is seen to rise to a maximum as digestion progresses, after which it falls to the optimum point of about 0.2 per cent. HCl.

Hydrochloric acid exerts its influence in a variety of ways. It is the main agent in the derivation of pepsin and rennin or pexin from their antecedent zymogen compounds, pepsinogen and pexinogen (Warren); it imparts activity to these ferments; it prevents and even arrests fermentative and putrefactive changes in the food by destroying microörganisms; it softens connective tissue, it dissolves and acidifies the proteins, thus making possible the subsequent action of pepsin.

The inorganic salts of the gastric juice are probably only incidental and play no part in the digestive process.

Mechanism of Secretion.—Modern investigations have established the fact that the production and the discharge of gastric juice is under the control of a nerve center situated in the medulla oblongata. From this center nerve fibers pass by way of the vagus nerve to the glands of the stomach. Division of this nerve is followed by a cessation in the flow of the juice. Stimulation of the peripheral end with induced electric currents at the rate of one or two per second causes the juice to be discharged. Nerve impulses therefore, discharged by this center descend the vagus nerve fibers to the glands and excite them to action.

The production and discharge of the gastric juice just preceding and during a meal is the result of the action of two different stimuli, a primary and a secondary.

The *primary* stimulus to gastric secretion, is a psychic state induced, on the one hand, by the sight or the odor of food especially if an individual is hungry and the food appetizing; and on the other hand by the mastication of food which is agreeable. The juice thus secreted is known as *psychic* or *appetite* juice. The quantity of the juice secreted will be proportional to the agreeable character of the psychic state and the thoroughness of mastication. As a result of the psychic states nerve impulses descend nerve fibers to the center in the medulla and excite it to increased activity.

The *secondary* stimulus to the gastric secretion is in all probability chemic in character and developed in the stomach or in its walls during digestive activity, inasmuch as the secretion takes place independent of nerve influences and after division of all afferent and efferent nerves that pass from and to the stomach. The results of experiments indicate that there is produced in the gastric mucous membrane of the pyloric portion of the stomach some chemic agent, which is absorbed into the blood and carried to the glands throughout the stomach. On reaching the glands this agent excites them to continuous activity. For this reason the agent has been termed the *gastric hormone* or *gastric secretin.* The stimulus to the production of the hormone is believed to be either the action of certain articles of food, *e.g.*, dextrin, meat broth or the first products of digestion.

Physiologic Action of Gastric Juice.—The principal action of the gastric juice is the transformation of the different protein principles of the food into *peptones*, the intermediate stages of which are due to the influence of the acid and pepsin respectively. As soon as any one of the proteins is penetrated by the acid it is converted into *acid-protein*, a fact which indicates that the first step in gastric digestion is the acidification of the proteins. This having been accomplished, the pepsin becomes operative and in a varying length of time transforms the acid-protein into a new form of protein termed *peptone*. In this transformation it is possible to isolate intermediate bodies by the addition of ammonium and magnesium sulphates, to which the term *proteoses* has been given. Because of the order in which they are obtained they have been divided into primary and secondary. This supposed change is represented by the following scheme:

Protein—Acid-protein—Proteose—Proteose—Peptone
(primary)—(secondary)

Peptones.—Peptones are the final products of the digestion of protein bodies in the stomach and differ from the bodies from which they are derived in the following particulars:

1. They are *diffusible—i.e.*, capable of passing readily through anima membranes.
2. They are *soluble* in water and in saline solution.
3. They are *non-coagulable* by heat and nitric or acetic acids. They can be readily precipitated, however, by tannic acid, by bile acids, and by mercuric chlorid.

The enzyme *rennin*, causes the caseinogen of milk to undergo a peculiar change before the acid and pepsin can convert it into peptone. This change consists in the cleavage of the caseinogen into a soluble protein and another body which combining with calcium salts forms casein. Casein then undergoes a chemic transformation similar to that of all other proteins.

The enzyme *lipase* is believed to digest fat when in a finely emulsified state in a manner similar to the corresponding enzyme of the pancreatic juice.

Movements of the Stomach.—During the period of gastric digestion the walls of the stomach become the seat of a series of movements, somewhat peristaltic in character, which serve not only to incorporate the gastric juice with the food, but also serve to eject the liquefied portions of the food into the intestine.

After the entrance of the food both the cardiac and pyloric orifices are closed by the contraction of their sphincters. Within five minutes (in the cat) annular constrictions begin in the pyloric region which move peristaltically toward the pylorus. As digestion proceeds these constrictions or contractions become more frequent and more vigorous. The result is a trituration and liquefaction of the food. So soon as it is liquefied the pylorus relaxes and permits of its discharge into the intestine. The pylorus then closes and further preparation of food goes on. From time to time the pylorus relaxes to permit the discharge of prepared and liquefied food until digestion is completed. The reason assigned for the relaxation of the sphincter muscle is the presence of a sufficient amount of free hydrochloric acid on the gastric side. The reason assigned for its contraction after the discharge of food into the duodenum is the presence of the hydrochloric acid in this region. With its neutralization by the alkalies there present, its influence in causing contraction of the sphincter gradually diminishes. In the cardiac region there is an absence of peristalsis though the muscle wall is in a state of active tone. The fundus acts as a reservoir for food and delivers its contents to the pyloric region as rapidly as it is ready to receive them.

Nerve Mechanism of the Stomach.—The muscle activities of the walls of the stomach as well as the activities of the sphincter muscles, viz., the sphincter cardiæ and sphincter pylori, are in part inaugurated and modified from time to time by the nerve system. In a general way it may be stated that the necessary muscle tonus is due to the action of the *vagus* nerve. Division of this nerve is followed by a loss of tonus. Stimulation causes an augmentation in the vigor of the contractions of the pyloric musculature, of the cardiac and fundus musculature and of the sphincters; an inhibition of these movements is brought about by stimulation of the splanchnic nerves.

The Duration of Gastric Digestion.—The length of time required for the digestion of a meal will depend largely on the quantity and the quality of the foods consumed. The relative digestibility of different articles of food was tested by Dr. Beaumont on a mass with a gastric fistula. The results of his observation were recorded in a table of which the following is an abstract.

TABLE SHOWING THE DIGESTIBILITY OF VARIOUS ARTICLES OF FOOD

	Hours	Minutes		Hours	Minutes
Eggs, whipped	1	20	Soup, barley, boiled.	11	30
Eggs, soft boiled.....	3	..	Soup, bean, boiled. .	3	
Eggs, hard boiled....	3	30	Soup, chicken, boiled	3	
Oysters, raw	2	55	Soup, mutton, boiled	3	30
Oysters, stewed	3	30	Sausage	3	20
Lamb, broiled.......	2	30	Green corn, boiled .	3	45
Veal, broiled	4	..	Beans, boiled.......	2	30
Pork, roasted	5	15	Potatoes, roasted. ..	2	30
Beefsteak, broiled....	3	..	Potatoes, boiled	3	30
Turkey, roasted	2	25	Cabbage, boiled	4	30
Chicken, boiled......	4	..	Turnips, boiled	3	30
Chicken, fricasseed ..	2	45	Beets, boiled	3	45
Duck, roasted.......	4	..	Parsnips, boiled	2	30

INTESTINAL DIGESTION

The physical and chemic changes which the food principles undergo in the small intestine, and which collectively constitute intestinal digestion, are complex and probably more important than those taking place in the stomach, for the food is, in this situation, subjected to the solvent action of the pancreatic and intestinal juices, as well as to the action of the bile, each of which exerts a transforming influence on one or more substances and still further prepares them for absorption into the blood.

To rightly appreciate the physiologic actions of the digestive juices poured into the intestine, the nature of the partially digested food as it comes from the stomach must be kept in mind. This consists of water, inorganic salts, acidified proteins, proteoses, peptones, starch, maltose, liquefied fat, saccharose, lactose, dextrose, cellulose, and the indigestible portion of meats, cereals, and fruits. Collectively they are known as chyme. As this acidified mass passes through the duodenum its contained acids excite a secretion and discharge of the intestinal fluids: *e.g.*, pancreatic juice, bile, and intestinal juice. Inasmuch as these fluids are alkaline in reaction they exert a neutralizing and precipitating influence on various constituents of the chyme. As soon as this has taken place, gastric digestion ceases and those chemic changes are inaugurated which eventuate in the transformation of all the remaining undigested nutritive materials into absorbable and assimilable compounds which collectively constitute intestinal digestion.

The Small Intestine.—This portion of the alimentary canal is a convoluted tube, measuring about seven meters in length and 3.5 cm. in diameter, and extending from the pyloric orifice of the stomach to the beginning of the large intestine.

The Walls of the Small Intestine.—The walls of the intestine consist of four coats: viz., serous, muscle, submucous, and mucous.

1. The *serous* coat is the most external and is formed by a reflection of the general peritoneal membrane.

2. The *muscle* coat surrounds the entire intestine and consists of two layers of fibers: 1. an external or longitudinal, and 2. an internal or circular. The longitudinal fibers form a thin layer all over the intestine. The circular fibers are much more numerous and completely surround the intestine throughout its entire extent.

3. The *mucous coat* is soft and velvety and is covered by a single layer of columnar epithelial cells. Its entire surface presents small conical projections termed villi.

Blood-vessels, Nerves, and Lymphatics.—The blood-vessels of the small intestine, which are very numerous, are derived mainly from the superior mesenteric artery. After penetrating the intestinal walls the smaller vessels ramify in the submucous coat and send branches to the muscle and mucous coats, supplying all their structures with blood. After circulating through the capillary vessels the blood is returned by small veins which subsequently unite to form the superior mesentericv ein, which, uniting with the splenic and gastric veins, forms the portal vein. The nerve elements in the intestinal wall consist of two plexuses, one (Auerbach's) lying between the muscle coats, the other (Meissner's) lying in the submucous coat. To this nerve net, composed of nerve cells and nerve processes, found in connection with the muscle coats of the stomach, of the small and of the large intestine as well, the term *myenteric plexus* has been given. The lymphatics, which originate in the mucous and muscle coats, are very abundant. They unite to form those vessels seen in the mesentery and empty into the thoracic duct.

Intestinal Glands.—The gland apparatus of the intestine by which the intestinal juice is secreted consists of the duodenal (Brunner's) and the intestinal (Lieberkühn's) glands.

The *duodenal glands* are situated beneath the mucous membrane and open by a short wide duct on its free surface. They are racemose glands lined by nucleated epithelium. The secretion of these glands is clear, slightly viscid, and alkaline. Its chemic composition and functions are unknown.

The *intestinal glands* or follicles are distributed throughout the entire mucous membrane in enormous numbers. They are formed mainly by an inversion of the mucous membrane and hence open on its free surface. Each tubule consists of a thin basement membrane lined by a layer of spheric epithelial cells, some of which undergo distention by mucin and become converted into mucous or goblet cells. The epithelial secreting cells consist of granular protoplasm containing a well-defined nucleus. The intestinal follicles constitute the apparatus which secretes the chief portion of the intestinal juice.

The Pancreas.—This gland is long, narrow and flattened and is situated deep in the abdominal cavity, lying just behind the stomach. It measures from fifteen to twenty centimeters in length, six in breadth, and two and a half in thickness. It is usually divided into a head, body, and tail.

The pancreas communicates with the intestine by means of a duct. This duct commences at the tail and runs transversely through the body of the gland. As it approaches the head of the gland it gradually increases in size until it measures about two or three millimeters in diameter. It then curves downward and forward and opens into the duodenum. In its course through the gland it receives branches which enter it nearly at right angles.

The pancreas is similar in structure to the salivary glands, and consists of the system of ducts terminating in acini. The acini are tubular or flask-shaped, and consist of a basement membrane lined by a layer of cylindric, conic cells, which encroach upon the lumen of the acini. The cells exhibit a difference in their structure (Fig. 8), and may be said to consist of two zones—viz., an *outer parietal zone*, which is transparent

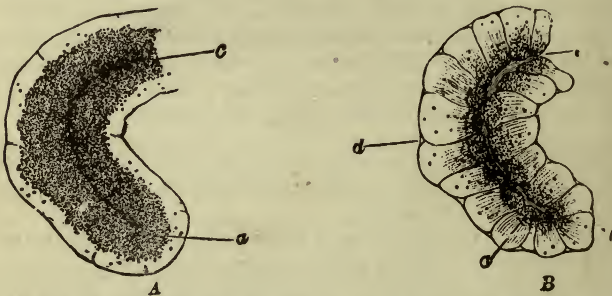

FIG. 8.—ONE SACCULE OF THE PANCREAS OF THE RABBIT IN DIFFERENT STATES OF ACTIVITY.—(*After Kühne and Lea.*)

A. After a period of rest, in which case the outlines of the cells are indistinct and the inner zone—*i.e.*, the part of the cells (*a*) next the lumen (*c*)—is broad and filled with fine granules. B. After the gland has poured out its secretion, when the cell outlines (*d*) are clearer, the granular zone (*a*) is smaller, and the clear outer zone is wider.

and apparently homogeneous, staining rapidly with carmin; an *inner zone*, which borders the lumen, and is distinctly granular and stains but slightly with carmin. These cells undergo changes similar to those exhibited by the cells of the salivary glands during and after active secretion. As soon as the secretory activity of the pancreas is established, the granules disappear, and the inner granular layer becomes reduced to a very narrow border, while the outer zone increases in size and occupies nearly the entire cell. During the intervals of secretion, however, the granular layer reappears and increases in size until the outer zone is reduced to a minimum. It would seem that the granular matter is formed by the nutritive processes occurring in the gland during rest, and is discharged during secretory activity into the ducts, and takes part in the formation of the pancreatic secretion.

Toward the outer extremity of the pancreas there are found among the acini collections of globular cells arranged in rods or columns separated by connective tissue. They have been termed after their discoverer, the Islands of Langerhans. It is believed they produce an internal secretion which in some way regulates sugar metabolism.

The Pancreatic Juice.—The pancreatic juice is transparent, colorless, strongly alkaline, and viscid, and has a specific gravity of 1,020. It is one of the most important of the digestive fluids, as it exerts a transforming influence upon all classes of alimentary principles, and has been shown to contain at least three distinct enzymes, viz., *amylopsin*, *trypsin*, *steapsin* or *lipase*. It has the following composition:

Composition of Pancreatic Juice

Water	900.76
Protein material	90.44
Inorganic salts	8.80
	1,000.00

Mode of Secretion.—The secretion and discharge of the pancreatic juice is associated with the introduction of food into the mouth and stomach and its early passage into the duodenum and is brought about by the action of a primary and a secondary stimulus.

The *primary* stimulus is a psychic state according to Pavlov induced by the sight, odor and taste of food and which leads to the discharge of nerve impulses from nerve-cells in the medulla oblongata and their transmission by efferent nerves in the trunk of the vagus nerve, to the cells of the acini. It is probable that the impressions made by the food on the criminal filaments of the afferent fibers in the vagus nerve develop nerve impulses which, when transmitted to the medulla, occasion the discharge of nerve impulses that not only excite the secretion but increase the blood-supply as well.

The *secondary* stimulus is chemic in character and developed in the glands of the mucous membrane of the duodenum by the action of the acids of the chyme, that is, of the digested foods, coming through the pylorus.

If an extract of the glandular portion of the duodenal mucous membrane, made with hydrochloric acid 0.4 per cent. is injected into the blood it evokes a profuse discharge of pancreatic juice. As hydrochloric acid alone will not produce this effect it is assumed that the extract contains an agent that excites or arouses the pancreas to secretor activity and to which, therefore, the name *secretin* is given. The secretin developed by the passage of the acid food over the surface of the mucous membrane is absorbed into the blood and carried eventually to the pancreas and brought into relation with the cells on which it exerts its stimulating action. This agent belongs to the class of *hormones*.

Physiologic Action.—By virtue of its contained enzymes pancreatic juice acts on:

1. On *Starch*.—When normal pancreatic juice or a glycerin extract of the gland is added to a solution of hydrated starch, the latter is speedily transformed into maltose, passing through the intermediate stage of dextrin. The process is in all respects similar to that observed in the digestion of starch by saliva. Pancreatic juice, however, is more energetic in this respect than saliva. The enzyme which effects this change is termed *amylopsin*. When the starch which escapes salivary digestion passes into the small intestine and mingles with pancreatic juice, it is very promptly converted into maltose by the action or in the presence of this enzyme.

2. On *Protein*.—The protein bodies which escape digestion in the stomach are converted into peptones by the action of the alkali and ferment. The first effect of the alkali is to change the protein into an *alkali-protein*, a fact which indicates that in the digestion of protein by pancreatic juice, the first stage is alkalinization. This having been accomplished, the ferment *trypsin* transforms the alkali-albumin into peptone. The addition of magnesium sulphate to the digestion mixtures causes a precipitation of an intermediate termed proteose. For this reason it is believed that here also peptones are preceded in their development by proteoses, of which there is probably, however, but one form, viz., secondary proteoses. Long-continued action of the pancreatic juice, decomposes the peptone into leucin, tyrosin, histidin aspartic acid, etc., compounds which belong to the group of bodies known as *amino-acids*, etc.

3. On *Fat*.—If pancreatic juice be added to a perfectly neutral fat—olein, palmitin, or stearin—and kept at a temperature of about 100°F. (38°C.), it will at the end of an hour or two be partially decomposed into glycerin and the particular fat acid indicated by the name of the fat used—*e.g.*, oleic, palmitic, stearic. The oil will then exhibit an acid reaction. The reaction is represented in the following formula:

$$\underset{\text{Triolein.}}{C_3H_5(C_{18}H_{33}O_2)_3} + \underset{\text{Water.}}{3H_2O} = \underset{\text{Oleic Acid.}}{C_{18}H_{34}O_2} + \underset{\text{Glycerin}}{C_3H_5(HO)_3}$$

If to this acidified oil there be added an alkali, *e.g.*, potassium or sodium carbonate, the latter will at once combine with the fat acid to form a salt known as a soap. The reaction is expressed in the following equation:

$$\underset{\text{Sodium Carbonate.}}{Na_2CO_3} + \underset{\text{Oleic Acid.}}{C_{18}H_{34}O_2} = \underset{\text{Sodium Oleate.}}{2NaC_{18}H_{33}O_2} + \underset{\text{Carbonic Acid.}}{H_2CO_3}$$

Coincident with the formation of the soap, the remaining portion of the neutral oil will undergo division into globules of microscopic size, which are held in suspension in the soap solution, forming what has been termed an *emulsion*, which is white and creamy in appearance. The cause of this minute subdivision of the fat and the necessity for it is unknown. It may be assumed that by virtue of the subdivision a greater surface is exposed to the action of the pancreatic enzyme and the digestion of the fat thereby facilitated. The action of the pancreatic juice may then be said to consist in the cleavage of the neutral fats into fatty acids and glycerin, after which the formation of the soap and the division of the fat takes place spontaneously. The enzyme which produces the cleavage of the neutral fats has been termed *steapsin or lipase.*

Physiologic Action of Intestinal Juice.—By reason of its contained enzymes intestinal juice acts:

1. On *Proteoses* and *Peptones.*—These bodies were supposed at one time to represent the final stages in the digestion of the proteins. This view is no longer entertained. It is now generally believed that under the influence of the intestinal juice they undergo a disruption into very simple bodies, known as *amino-acids.* This disruption is brought about by an agent termed *erepsin.* Inasmuch as the long-continued action of pancreatic juice also disrupts the peptones, it is also believed to contain erepsin.

2. On *The Compound Sugars.*—Saccharose, maltose and lactose, the three compound sngars, are believed by most observers to be not only non-absorbable, but also non-assimilable and, therefore, are required to undergo some digestive change before they can be absorbed and assimilated. An extract of the intestinal mucous membrane or the intestinal juice of the dog added to a solution of saccharose will cause it to combine chemically with water after which a cleavage into dextrose and levulose will take place, which together constitute *invert* sugar. The enzyme to which this action is attributed has been termed *invertase* or *saccharase.* Maltose undergoes a similar change. After its combination with water it undergoes a cleavage into two molecules of dextrose. Lactose appears to be unaffected by the pure juice. As it is non-assimilable it has been supposed to undergo conversion into dextrose and galactose while passing through the epithelial cells of the intestinal mucosa. In either case the

transformation is brought about by two ferments known respectively as *maltase* and *lactase.*

3. On *Trypsinogen.*—This zymogen when first discharged from the pancreatic duct is inactive and incapable of effecting the necessary digestive changes in the proteins. Shortly after its entrance into the intestine, it becomes quite active and efficient, a change attributed to an agent *entero-kinase* secreted by the mucosa in the upper part of the intestine.

The Bile.—This fluid is a product of the secretor activity of the liver-cells. After its formation by the liver cells it is conveyed from the liver by the bile capillaries which unite finally to form the main hepatic duct. This duct emerges from the liver at the transverse fissure. At a distance of about 5 centimeters it is joined by the cystic duct, the distal extremity of which expands into a pear-shaped reservoir, the *gall-bladder* in which the bile is temporarily stored. The duct formed by the union of the hepatic and cystic ducts, the common bile-duct, passes downward and forward for a distance of about 7 centimeters, pierces the walls of the intestine and passes obliquely through its coats for about a centimeter and opens into a small receptacle, the ampulla of Vater.

Physical Properties.—The bile coming from the liver is thin and watery. That obtained from the gall-bladder is more or less viscid from the presence of mucin. The specific gravity of human bile varies within normal limits from 1.010 to 1.020. The reaction is invariably alkaline in the human subject when first discharged from the liver, but may become neutral in the gall-bladder. The alkalinity depends on the presence of sodium carbonate and sodium phosphate. When fresh, it is inodorous; but it readily undergoes putrefactive changes, and soon becomes offensive. Its taste is decidedly bitter. When shaken with water, it becomes frothy —a condition which lasts for some time and which is due to the presence of mucin. In ox bile the mucin is replaced by a nucleo-protein.

The color of bile obtained from the hepatic duct is variable, usually a shade between a greenish yellow and a brownish red. In different animals the color varies. In the herbivorous animals it is usually green; in the carnivorous animals it is orange or brown. In man it is green or a golden yellow. The colors are due to the presence of pigments. Microscopic examination fails to show the presence of structural elements.

Chemic Composition.—Human bile obtained from an accidental biliary fistula was shown by Jacobson to contain the following ingredients, viz.:

Composition of Human Bile

Water	977.40
Sodium glycocholate	9.94
Sodium taurocholate	a trace
Cholesterol	0.54
Free fat	0.10
Sodium palmitate and stearate	1.36
Lecithin	0.04
Organic matter, and pigments bilirubin and biliverdin	2.26
Inorganic salts	8.36
	1,000.00

Sodium glycocholate and *sodium taurocholate* are the characteristic biliary salts. They are compounds of sodium and glycocholic and taurocholic acids. There is evidence that the former is formed by the union of an amino-acid glycocoll and cholic acid, and that the latter is formed by the union of taurin, a derivative of the amino-acid cystin, both of which are absorbed from the intestines. The origin of cholic acid is not clear.

There is good evidence for the view, that after their discharge into the intestine, the bile salts are absorbed, with the exception of a portion destroyed by bacteria, and carried by the portal vein to the liver and again excreted. By this circulation from liver to intestine and from intestine to the liver, the work of the liver cells in the synthesis or secretion of bile acids, is supposed to be reduced to a minimum. It is also probable that a portion of the acids enters the general circulation and influences favorably the general nutrition. It is stated by some investigators that the activities of the liver cells are decidedly increased by the circulation of the bile salts and that they are to be regarded as the natural stimuli to the secretion.

Cholesterol.—Cholesterol when obtained from bile presents itself in the form of flat rectangular crystals. Though a constant constituent of bile, is not confined to this fluid as it has been shown to be a normal constituent of all animal and vegetable cells, though it is particularly abundant in the myelin of nerve-fibers. Though cholesterol has for a long time been regarded merely as one of the products of the katabolism of living material, it has come to be believed that it is necessary to the vitality of tissue cells and especially to the blood cells. Entering into the composition of the surface layer of cells, it prevents the entrance of certain toxins which would have a destructive influence on their structure or composition. In the metabolism of cells it is set free after which it passes into the blood to be secreted by the liver. In the bile it frequently undergoes crystallization and forms one of the forms of gall-stones. In the bile the cholesterol is held in solution by the biliary salts. In the intestine it is converted into stercorin and discharged in the feces.

Bilirubin, Biliverdin.—These two pigments impart to the bile its red and green colors respectively. Bilirubin is present in the bile of human beings and the carnivora, biliverdin in the bile of the herbivora. As the former pigment readily undergoes oxidation in the gall-bladder, giving rise to the latter pigment, almost any specimen of bile may present any shade of color between red and green. Bilirubin is regarded as a derivative of hematin, one of the cleavage products of hemoglobin, the coloring-matter of the blood. In the liver the hematin combines with water, loses its iron, and is changed to bilibrubin. By continuous oxidation there are formed biliverdin, bilicyanin, and choletelin. After their discharge into the intestine the bile pigments are finally reduced to hydrobilirubin or an allied substance, stercobilin, which becomes one of the constituents of the feces. A portion of the latter is absorbed into the blood and ultimately discharged into the urine where it is known as urobilin.

Lecithin.—Lecithin is regarded, because of its physical properties and chemic composition, as a complex fat. When pure it presents itself generally as a white crystalline powder, though very frequently as a white waxy mass which is soluble in ether and alcohol. Lecithin is widely distributed throughout the body, being found in blood, lympth, red and white corpuscles, nerve-tissue, yolk of egg, semen, milk, and bile. Lecithin has been regarded as one of the decomposition products of nerve-tissue, removed from the blood by the liver and thus becoming one of the constituents of the bile, in which it is held in solution by the bile salts. Lecithin can be readily decomposed by various agents yielding glycophosphoric acid, a fat acid and cholin.

The Mode of Secretion and Discharge of Bile.—The flow of bile from the liver is continuous but subject to considerable variation during the twenty-four hours. The introduction of food into the stomach at once causes a slight increase in the flow, but it is not until about two hours later that the amount discharged reaches its maximum; after this period it gradually decreases up to the eighth hour, but never entirely ceases. During the intervals of digestion though a small quantity passes into the intestine, the main portion is diverted into the gall-bladder, because of the closure of the common bile-duct by the sphincter muscle near its termination, where it is retained until required for digestive purposes. When acidulated food passes over the surface of the duodenum, there is an increase in the secretion or at least the discharge of bile, due to the relaxation of the sphincter muscle of the common bile-duct and the contraction of the muscle walls of the gall-bladder and biliary passages.

Physiologic Action of Bile.—The exact relation of the bile to the digestive process has not been satisfactorily determined. No specific action can be attributed to it. It has but a slight, if any, diastatic action on starch. It is without influence on proteins or on fats directly. But indirectly and by virtue of the bile salts it contains, it plays an important part in increasing the action of the pancreatic enzymes. Thus the amylolytic or starch transforming power of the pancreatic juice is almost doubled and the same is true for its proteolytic power, while its lipolytic or fat-splitting power is tripled.

The bile salts also dissolve insoluble soaps which may be formed during digestion and thus favors the digestion of fat. If it be excluded from the intestine there is found in the feces from 22 to 58 per cent. of the ingested fats. At the same time the chyle, instead of presenting the usual white creamy appearance, is thin and slightly yellow. The manner in which the bile promotes fat digestion is yet a subject of investigation. If all the fat is converted into fat acids and glycerin, with the formation of soaps, as seems probable, the action of the bile becomes more apparent from the fact, already stated, that it dissolves and holds in solution the soaps so formed which would be necessary to their absorption by the epithelial cells. This action has been attributed to the presence of the bile salts. As an aid to digestion the bile has been regarded as important, for the reason that its entrance into the intestine is attended by a neutralization and precipitation of the proteins which have not been fully digested and are yet in the stage of acid-albumin. In this way gastric digestion is arrested and the foods are prepared for intestinal digestion.

Though bile possesses no antiseptic properties outside the body, itself undergoing putrefactive changes very rapidly, it has been believed that in the intestine it in some way prevents or retards putrefactive changes in the food. There can be no doubt that if the bile is prevented from entering the intestine there is an increase in the formation of gases and other products which impart to the feces certain characteristics which are indicative of putrefaction. As to the manner in which bile retards this process nothing definite can be stated. It has been supposed to be a stimulant to the peristaltic movements of the intestine, inasmuch as these movements diminish when bile is diverted from the intestine.

Intestinal Movements.—During intestinal digestion the walls of the intestine exhibit two kinds of movement, viz., a rhythmic segmentation and a peristalsis. By the former the food is divided into segments and by the latter, it is carried down the intestine. Shortly after the entrance of food into the duodenum a broad peristaltic wave promptly carries it downward a variable distance a rhythmic segmentation begins by a contraction of bands of circular muscle fibers. So soon as a mass of food is divided into segments each segment is in turn again divided by similar contractions. The lower half of each segment then unites with the upper half of the segment below to commingle with it and to expose new surfaces of the food mass to contact with the intestinal juices and to the mucous membrane. A continual repetition of this process results in a thorough mixing of the food with the digestive juices. Subsequent peristaltic waves slowly carry the food further down the intestine, after which a further segmentation takes place. These alternate movements continue throughout the digestive process.

The Nerve Mechanism of the Small Intestine.—The rhythmic segmentation movements are the result of an intraintestinal pressure due to the accumulation of food, provided the intestinal walls possess the requisite degree of tonicity. The tonicity is imparted to the muscle coat by nerve impulses coming from the central nerve system through the efferent vagus nerve fibers. The orderly and coördinated contractions and relaxations of the muscle coat which constitute a peristaltic movement are mediated by the myenteric plexus—the nerve plexus of Meissner and Auerbach—and therefore termed a myenteric reflex.

The intestine is connected with the central nerve system by the vagi and splanchnic nerves, both of which influence the tonus and the vigor of the intestinal contractions in one direction or the other. Thus stimulation of the vagus nerve increases the contractions, while stimulation of the splanchnic inhibits the contractions. The degree of activity of the intestine at any one moment is the resultant of the opposing actions of these two nerves.

The Large Intestine.—The large intestine is that portion of the alimentary canal situated between the termination of the ileum and the anus. It varies in length from one and a quarter to one and a half meters, in diameter from three and a half to seven centimeters. It is divided into the cecum, the colon (subdivided into an ascending, transverse, and descending portion, including the sigmoid flexure), and the rectum.

The walls of the large intestine consist of three coats: viz., serous, muscular, and mucous.

The *serous* is a reflection of the general peritoneal membrane.

The *muscle* is composed of both longitudinal and circular fibers. The longitudinal fibers are collected into three narrow bands which are situated at points equidistant from one another. At the rectum they spread out so as to surround it completely. As the longitudinal bands are shorter than the intestine itself, its surface becomes sacculated, each sac being partially separated from adjoining sacs by narrow constrictions. The circular fibers are arranged in the form of a thin layer over the entire intestine. Between the sacculi, however, they are more closely arranged. The sacculi have been termed *haustra* from their supposed function, that of absorbing or drawing water from the intestinal contents thus imparting to them a certain degree of consistency. In the rectum the circular fibers are well developed, and at a point an inch above the anus they form, as stated above, the *internal* sphincter.

The *mucous membrane* of the large intestine possesses neither villi nor valvulæ conniventes. It contains a large number of tubules consisting of a basement membrane lined by columnar epithelium. They resemble the follicles of Lieberkühn. The secretion of these glands is thick and viscid and contains a large quantity of mucin.

The Movements of the Large Intestine.—After the absorption of the prepared food materials, the remaining contents of the intestine, together with certain intestinal secretions and the excrementitious matter of the bile, pass into the large intestine and assist in the formation of the feces.

Under the influence of a peristaltic movement similar to that witnessed in the small intestine, all this excrementitious matter, deprived by absorption of the excess of its contained water and nutritive material, is gradually carried downward to the sigmoid flexure, where it accumulates prior to its extrusion from the body. The effects of the peristaltic waves are to some extent interfered with by *anti-peristaltic* or *anastaltic* waves which, beginning in the transverse colon, run toward and to the cecum. An antiperistaltic wave occurs in the cat about every fifteen minutes and lasts for about five minutes. The intestinal contents are thereby driven back toward the cecum. The effect is a still further admixture with the secretions and exposure to the absorbing mucosa.

In addition to the anastaltic waves, contractions of the haustra have been observed which resemble the segmentation contractions observed in the small intestine and which promote it is believed the absorption of water from the intestinal contents.

The Function of the Large Intestine.—The function of the large intestine is therefore to receive, to reduce to a proper consistency, to temporarily store and subsequently discharge its contents, consisting of the indigestible residue of the food, together with excretions of intestinal glands which have descended from the small intestine and which constitute in part the feces.

Intestinal Fermentation.—Owing to the favorable conditions in both the small and large intestine for fermentative and putrefactive processes—

e.g., heat, moisture, oxygen, and the presence of various microörganisms—the food, when consumed in excessive quantity of when acted on by defective secretions, undergoes a series of decomposition changes which are attended by the production of gases and various chemic compounds. Among the more important of these compounds may be mentioned indol, skatol, cresol and phenol. They arise from the putrefactive decomposition of various amino-acids. A certain portion of each is eliminated in the feces while another portion is absorbed into the portal circulation, oxidized, and combined with potassium sulphate. By this means their toxicity is destroyed. They are subsequently eliminated in the urine. The amount of the potassium indoxyl sulphate or *indican* in the urine is taken as a meature of the extent of intestinal putrefaction.

The Feces.—The feces is a term applied to the mass of material ejected from the rectum through the anus. They are characterized by consistency, color and odor, properties which are connected with the rapidity with which they are carried through the intestine, the quality of the food, and the extent of the fermentative and putrefactive changes they undergo.

Defecation.—Defecation is the voluntary act of extruding the feces from the rectum, and is accomplished by a relaxation of the sphincter ani muscle and by the contraction of the muscular walls of the rectum, aided by the contraction of the abdominal muscles.

ABSORPTION

The term absorption is applied to the passage or transference of materials into the blood from the tissues, from the serous cavities, and from the mucous surfaces of the body. The most important of these surfaces, especially in its relation to the formation of blood, is the mucous surface of the alimentary canal; for it is from this organ that new materials are derived which maintain the quality and quantity of the blood. The absorption of materials from the interstices of the tissues is to be regarded rather as a return to the blood of liquid nutritive material which has escaped from the blood-vessels for nutritive purposes, and which, if not returned, would lead to an accumulation of such fluid and the development of dropsical conditions.

The anatomic mechanisms involved in the absorptive processes are, primarily, the *lymph-spaces*, the *lymph-capillaries*, and the *blood-capillaries* secondarily, the *lymphatic vessels* and *larger blood-vessels.*

Lymph-spaces, Lymph-capillaries, Blood-capillaries.—Everywhere throughout the body, in the intervals between connective-tissue bundles and in the interstices of the several structures of which an organ is composed, are found spaces of irregular shape and size, determined largely by the nature of the organ in which they are found, which have been termed *lymph-spaces* or *lacunæ*, from the fact that during the living condition they are continually receiving the lymph which has escaped from the blood vessels throughout the body. In addition to the connective-tissue lymph-spaces, various observers have described special lymph-spaces in the testicle, kidney, liver, thymus gland, and spleen; in all secreting glands between the basement membrane and blood-vessels; around blood-vessels (perivascular spaces), and around nerves. The *serous cavities* of the body —peritoneal, pleural, pericardial, etc.—may also be regarded as lymph-spaces, which are in direct communication by open mouths or *stomata* with the lymph capillaries. This method of communication is not only true of serous membranes, but to some extent also of mucous membranes, The cylindric sheaths and endothelial cells surrounding the brain, spinal cord, and nerves can also be looked upon as lymph-spaces in connection with lymph-capillaries.

The *blood-capillaries* not only permit the passage of the liquid nutritive portions of the blood across their delicate walls, but are also engaged in the reabsorption of this transudate, as well as in the absorption of new materials from the alimentary canal. The extensive capillary network which is formed by the ultimate subdivision of the arterioles in the submucous tissue and villi of the small intestine forms an anatomic arrangement well adapted for absorption. It is now well known that in the obsorption of the products of digestion the blood-capillaries are more active than the lymph-capillaries.

The Blood-vessels.—The blood-vessels which are concerned in the conduction of fresh nutritive material from the alimentary canal have their origin in the elaborate capillary network in the mucous membrane. The small veins which emerge from the network gradually unite, forming larger and larger trunks, which are known as the gastric, superior, and inferior mesenteric veins. These finally unite to form the portal vein, a short trunk about three inches in length. The portal vein enters the liver at the transverse fissure, after which it forms a fine capillary plexus ramifying throughout the substance of the liver; from this plexus the hepatic veins take their origin, and finally empty the blood into the vena cava inferior. (See Fig. 9.)

The *lymph-capillaries*, in which the lymph-vessels proper take their origin, are arranged in the form of plexuses of quite irregular shape. In most situations they are intimately interwoven with the blood-vessels, from which, however, they can be readily distinguished by their larger caliber and irregular expansions. The wall of the lymph-capillary is formed by a single layer of epithelioid cells, with sinuous outlines, and which accurately dove-tail with one another. In no instance are valves found. In the villus of the small intestine the beginning of the lymphatic is to be regarded as a lymph-capillary, generally club-shaped, which at the base of the villus enters a true lymphatic; at this point a valve is situated, which prevents regurgitation. The lymph capillaries anastomose freely with one another, and communicate on the one hand with the lymph-spaces, and on the other with the lymphatic vessels proper.

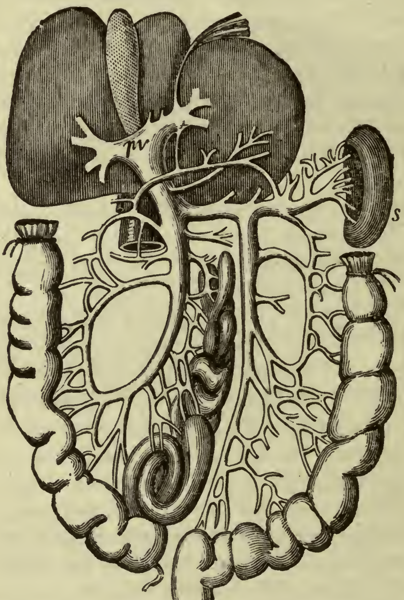

FIG. 9.—Diagram of the portal vein (*pv*) arising in the alimentary tract and spleen (*s*) and carrying the blood from these organs to the liver.—(*Yeo's "Text-book of Physiology."*)

As the shape, size, etc., of both lymph-spaces and capillaries are determined largely by the nature of the tissues in which they are contained, it is not always possible to separate the one from the other. Their function, however, may be regarded as similar—viz., the collection of the lymph which has escaped from the blood-vessels, and its transmission onward into the regular lymphatic vessels.

Lymph-vessels.—These constitute a system of minute, delicate transparent vessels, found in nearly all the organs and tissues of the body.

Having their origin at the periphery in the lymph-capillaries and spaces, they rapidly converge toward the trunk of the body and empty into the thoracic duct. In their course they pass through numerous small ovoid bodies, the lymphatic glands.

The lymph-vessels of the small intestines—*the lacteals*—arise within the villus processes which project from the inner surface of the intestine throughout its entire extent. The wall of the villus is formed by an elevation of the basement membrane, and is covered by a layer of columnar epithelial cells. The basis of the villus consists of adenoid tissue, a fine plexus of blood-vessels, unstriped muscle-fibers, and the lacteal vessel. The adenoid tissue consists of a number of intercommunicating spaces, containing leukocytes. The lacteal vessel possesses a thin but distinct wall composed of endothelial plates, with here and there openings which bring the interior of the villus into communication with the spaces of the adenoid tissue.

The *structure* of the larger vessels resembles that of the veins, consisting of three coats:

1. *External*, composed of fibrous tissue and muscle fibers, arranged longitudinally.

2. *Middle*, consisting of white fibers and yellow elastic tissue, non-striated muscle-fibers, arranged transversely.

3. *Internal*, composed of an elastic membrane, lined by endothelial cells.

Throughout their course are found numerous *semilunar valves*, opening toward the larger vessels, formed by a folding of the inner coat and strengthened by connective tissue.

Lymph Glands.—The lymph glands consist of an external capsule composed of fibrous tissue which contains non-striped muscle-fibers; from its inner surface septa of fibrous tissue pass inward and subdivide the gland-substance into a series of compartments, which communicate with one another. The blood-vessels which penetrate the gland are surrounded by fine threads, forming a follicular arrangement, the meshes of which contain numerous lymph-corpuscles. Between the follicular threads and the wall of the gland lies a lymph-channel traversed by a reticulum of adenoid tissue. The lymph-vessels, after penetrating this capsule, pour their lymph into this channel, through which it passes; it is then collected by the efferent vessels and transmitted onward. The lymph-corpuscles which are washed out of the gland into the lymph-stream are formed, most probably, by division of preëxisting cells.

The Thoracic Duct.—The thoracic duct is the general trunk of the lymphatic system; into it the vessels of the lower extremities, of the abdominal organs, of the left side of the head, and of the left arm empty their contents. It is about fifty mm. in length, arises in the abdomen, opposite the third lumbar vertebra, by a dilatation (the *receptaculum chyli*), ascends along the vertebral column to the seventh cervical vertebra, and terminates in the venous system at the junction of the internal jugular and subclavian veins on the left side. The lymphatics of the right side of the head, of the right arm, and of the right side of the thorax terminate in the *right thoracic duct*, about one inch in length, which joins the venous system at the junction of the internal jugular and subclavian on the right side.

The general arrangement of the lymph vessels is shown in figure 10.

Lymph.—Lymph is a clear colorless fluid found in the tissue spaces and in the lymph vessels. The former is termed *intercellular*, the latter *intravascular*.

Physical Properties and Chemic Composition.—Lymph is clear, colorless, alkaline in reaction, saline to the taste and has a specific gravity varying from 1.020 to 1.030. It holds in suspension a number of corpuscles resembling in their general appearance the white corpuscles of the blood. Their number has been estimated at 8,200 per cubic millimeter, though the number varies in different portions of the lymphatic system. As the lymph flows through the lymphatic gland it receives a large addition of corpuscles. Lymph-corpuscles are granular in structure, and measure 1/2,500 of an inch in diameter. When withdrawn from the vessels, lymph undergoes a spontaneous coagulation similar to that of blood, after which it separates in serum and clot.

Chemic analysis shows that it consists of water, proteins 3 to 4 per cent., fat 0.004 to 0.13 per cent., sugar, 0.10 to 0.15 per cent., inorganic salts, 0.8 to 0.9 per cent., urea CO_2 and other katabolic products are present in small amounts.

Origin and Functions of Intercellular Lymph.—Though the blood is the common reservoir of all nutritive materials, they are not available for nutritive purposes as long as they are confined within the blood-vessels. But owing to the character of the wall of the capillary blood-vessels, some of the constituents of the blood-plasma pass across it and are received by the tissue-spaces in which they come into contact with the tissue-cells. To the sum total of these materials the term lymph is given. The forces concerned in the passage of the constituents of the lymph across the capillary wall are diffusion, osmosis and filtration. Other forces have been suggested such as the secretory activity of the capillary cells and the increased concentration of the lymph due to the accumula-

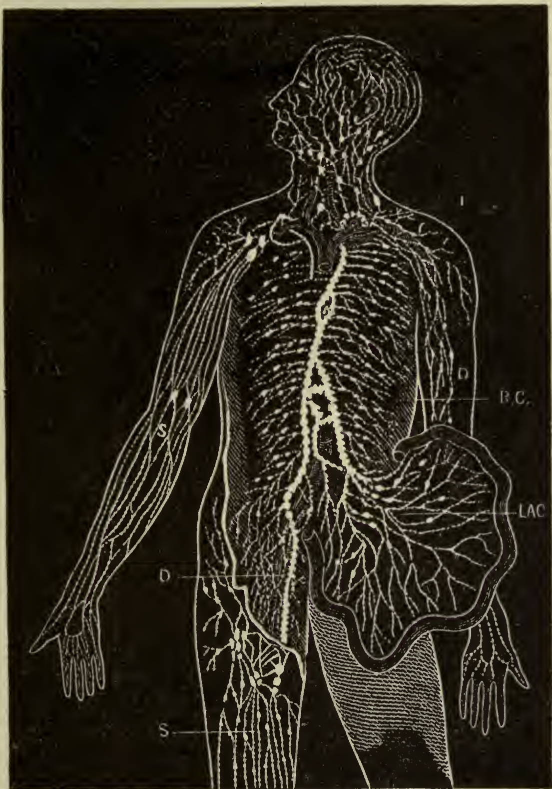

FIG. 10.—DIAGRAM SHOWING THE COURSE OF THE MAIN TRUNK OF THE ABSORBENT SYSTEM.—(*Yeo's "Textbook of Physiology."*)

The lymph-vessels of lower extremities (D) meet the lacteals of intestines (LAC at the receptaculum chyli (RC), where the thoracic duct begins. The superficial vessels are shown in the diagram on the right arm and leg (S), and the deeper ones on the arm to the left (D). The glands are here and there shown in groups. The small right duct opens into the veins on the right side. The thoracic duct opens into the union of the great veins of the left side of the neck (T).

tion of katabolic products whereby the osmotic pressure is increased. Its function becomes apparent from its origin and composition, its situation and relation to the tissues. It is to furnish the tissue-cells with those nutritive materials which are necessary for their growth, repair and functional activity. It also receives all waste products that arise from their activity prior to their removal by the blood- and lymph-vessels.

Absorption of Intercellular Lymph.—From the fact that lymph is being discharged more or less continuously from the thoracic duct, it is evident that lymph is being absorbed from the intercellular spaces; from which it may be inferred that more lymph is passing from the blood into the tissue-space than is necessary for the immediate needs of the tissues. To prevent an accumulation and an interference through pressure, with the activities of the tissues, the excess is absorbed by the lymph-vessels and returned to the blood stream by way of the thoracic duct. It is likely that some of the constituents are also absorbed by the blood-vessels.

Absorption of Food.—Physiological experiments have demonstrated that the agents concerned in the absorption of new materials from the alimentary canal are:

1. The *blood-vessels* of the entire canal, but more particularly those uniting to form the portal vein.

2. The *lymph vessels* coming from the small intestine, which converge to empty into the thoracic duct.

As a result of the action of the digestive fluids upon the different classes of food principles—proteins, sugars, starches, and fats—there are formed *amino-acids*, *dextrose* and *levulose*, *soap* and *glycerin*, which differ from the former in being highly diffusible—a condition essential to their absorption.

Their absorption is accomplished by the villous processes covering the surface of the intestinal mucous membrane.

The Villi.—The villi are small filiform or conical processes projecting from the surface of the mucous membrane. Each villus consists of a basement membrane supporting columnar epithelial cells. In the interior of the villus there is frame work of connective tissue supporting arteries, capillaries and veins and a single club-shaped lymph capillary.

Function of the Villi.—The villi, and especially the epithelial cells covering them, are the essential agents in the absorption of the products of digestion. It is by the activity of these cells that the new materials are taken out of the alimentary canal and transferred into the lymph-spaces in the interior of the villi, from which they are subsequently removed by the blood-vessels and lymph-vessels.

The water and inorganic salts and sugars after their absorption by the epithelium of the villi pass onward into the interior of the villi; thence across the capillary wall into the blood by which they are carried to the liver. The water and salts in all probability pass directly through the liver to become part of the general blood volume. The sugar is in part removed from the blood stream and temporarily stored in the liver cells under the form of starch. As it subsequently is transformed into glycose or glucose it was termed *glycogen*. The products of protein digestion—the amino-acids—are also absorbed by the epithelial cells. It was until recently believed that during their transit through the cell they were synthesized into plasma-albumin which was then discharged into the blood stream. More recent experiments indicate that this is not the case and that the amino-acids pass directly into and are found circulating in the blood.

The products of fat digestion—soap and glycerin—after absorption are synthesized to fat which is deposited in the epithelial cells in the form of small drops, after which it too passes to the interior of the villus to enter the lymph capillary.

The *products of digestion* find their way into the general circulation by two routes:

1. The *water*, *protein*, *dextrose*, and *soluble salts*, after passing into the lymph-spaces of the villi, pass across the wall of the capillary blood-vessel; entering the blood, they are carried to the liver by the vessels uniting to form the portal vein, Fig. 9; emerging from the liver, they are emptied into the inferior vena cava by the hepatic vein.

2. The *fat* enters the lymph-capillary in the interior of the villus; by the contraction of the layer of muscle-fibers surrounding it, its contents are forced onward into the lymph-vessels, thence into the thoracic duct, and finally into the blood stream at the junction of the internal jugular and subclavian veins on the left side, Fig. 10.

Chyle.—Chyle is the fluid found in the lymph vessels, coming from the small intestine after the digestion of a meal containing fat. In the intervals of digestion the fluid of these lymphatics is identical in all respect with the lymph found in all other regions of the body. As soon as the granular fat passes into the lymph vessels and mingles with the lymph it becomes milky white in color, and the vessels which previously were invisible become visible, and resemble white threads running between the layers of the mesentery. Chyle has a composition similar to that of lymph, but it contains, in addition, numerous fatty granules. When examined microscopically, the chyle presents a fine molecular basis, made up of the finely divided granules of fat.

Forces Aiding the Movement of Lymph and Chyle.—The lymph and chyle are continually moving in a progressive manner from the periphery or beginning of the lymphatic system to the final termination of the thoracic duct. The force which primarily determines the movement of the lymph has its origin in the beginnings of the lymph-vessels, and depends upon the difference in pressure here and the pressure in the thoracic duct. The greater the quantity of fluid poured into the lymph-spaces, the greater will be the pressure and, consequently, the movement. The first movement of chyle is the result of a contraction of the muscle-fibers within the walls of the villus. At the time of contraction the lymph capillary is compressed and shortened, and its contents are forced onward into the true lymphatic. When the muscle-fibers relax, regurgitation is prevented by the closure of the valve in the lymphatic at the base of the villus.

As the walls of the lymph vessels contain muscle-fibers, when they become distended these fibers contract and assist materially in the onward movement of the fluid.

The contraction of the general muscular masses in all parts of the body, by exerting an intermittent pressure upon the lymphatics, also hastens the current onward; regurgitation is prevented by the closure of valves which everywhere line the interior of the vessels.

The respiratory movements aid the general flow of both lymph and chyle from the thoracic duct into the venous blood. During the time of an inspiratory movement the pressure within the thorax, but outside the lungs, undergoes a diminution in proportion to the extent of the movement; as a result, the fluid in the thoracic duct outside of the thorax, being under a higher pressure, flows more rapidly into the venous system. At the time of an expiration, the pressure rises and the flow is temporarily impeded, only to begin again at the next inspiration.

THE BLOOD

The blood may be defined as the nutritive fluid of the body since it contains all those materials that are necessary to the maintenance of the nutrition. The presence and proper circulation of the blood in the living organism are essential for the maintenance of tissue irritability and for the manifestation of the activities of all physiologic mechanisms. The escape of the blood from the vessels, especially in the higher animals, is followed by cessation of the physiologic activities of all the tissues within a short period. The irritability, however, persists for a variable length of time though it too gradually declines and finally disappears. The blood is also a reservoir for the reception of katabolic products produced by and absorbed from the tissues.

The Physical Constitution of Blood.—A microscopic examination of the blood as it flows through the capillary vessels of the web of the frog or the mesentery of the rabbit shows that it is not a homogenous fluid, but that it consists of two distinct portions, viz.: (1) a clear, transparent, slightly yellow fluid, the *plasma* or *liquor sanguinis:* (2) small particles termed corpuscles floating in it, of which there are two varieties, the *red* or the *erythrocytes* and the *white* or the *leukocytes.* By appropriate methods it can be shown that a third corpuscle, colorless in appearance and smaller in size than the ordinary white corpuscle, is present in the blood stream and known as the *blood-platelet* or *plaque*.

Physical Properties.—The *color* of the blood in the arteries is scarlet red, in the veins bluish red. The cause of the color is the presence of a coloring matter, hemoglobin, in different degrees of combination with oxygen. As the venous blood passes into and through the pulmonic capillaries the hemoglobin absorbs a certain volume of oxygen after which it changes in color and on emerging from the lungs imparts to the blood its characteristic scarlet-red color. By reason of the union of the hemoglobin with the oxygen it is generally termed while in the arteries, oxyhemoglobin. As the arterial blood passes into and through the systemic capillaries, the oxyhemoglobin yields up a portion of its oxygen to the tissues after which it again changes in color and on emerging from the tissues imparts to the blood its characteristic bluish-red color. By reason of the loss of a portion of its oxygen, the hemoglobin is generally termed while in the veins, deoxy- or reduced hemoglobin.

The *opacity* of the blood or the inability to see objects through it, is the result of the dissipation of light, caused by the shape of the red corpuscles.

The *specific gravity* within the limits of health, ranges from 1.045 to 1.075 though the average is about 1.056.

The *reaction* of the blood is stated to be slightly alkaline because of the fact, as determined by the methods of physical chemistry, there is a preponderance of the hydroxyl ions over the hydrogen ions. The alkaline bases introduced into the blood in the foods are always in excess of the acids produced under physiological conditions and hence they constitute an "alkaline reserve." The physiologic action of this reserve is to combine with and remove from the body the acids, *e.g.*, sulphuric and phosphoric acids that arise during the metabolism of the proteins.

The *temperature* varies in different regions. In the aorta it is approximated 38.6°C.; in the portal vein 39°C.; in the hepatic veins 39.7°C.

The *viscosity* or the resistance to the movement of the molecules of the plasma among themselves, together with that of the corpuscles, is considerable. Compared with distilled water the viscosity of human blood is 4.5 times as great. The viscosity is increased and decreased by a rise or fall in the number of red corpuscles. In a case of polycythemia, the red corpuscle count was 11,000,000 per cubic millimeter and the viscosity 3 and 4 times the normal.

Coagulability.—When blood is withdrawn from the body and allowed to remain at rest, it becomes somewhat thick and viscid in from three to five minutes; this viscidity gradually increases until the entire volume of blood assumes a jelly-like consistence, which process occupies from five to fifteen minutes.

If a portion of such a jelly-like mass be examined microscopically, it will be found to be penetrated in all directions by a felt-work of extremely fine delicate fibrils, which, having made their appearance before the corpuscles have had time to settle to the bottom of the fluid, have entangled them in the meshes so that the entire mass retains its characteristic color. These fibrils are collectively known as fibrin. The appearance of the fibrin is, therefore, the cause of the coagulation.

As soon as coagulation is completed, a second process begins, which consists in the contraction of the coagulum and the oozing of a clear, straw-colored liquid—the *serum*—which gradually increases in quantity as the *clot* diminishes in size, by contraction, until the separation is completed, which occupies from twelve to twenty-four hours.

The Cause of Coagulation.—Coagulation is due to the appearance of fibrin, a compound formed by a physico-chemic union of an organic colloidal body, *thrombin*, with fibrinogen, this latter substance being always present in the blood. Thrombin is believed to be a derivative of an antecedent substance prothrombin or thrombogen, a substance always present in the blood and is a product of the decomposition of leukocytes and the blood-platelets. With thrombin there is associated a calcium salt which is essential for coagulation. If it is removed by the addition of potassium oxalate coagulation does not take place. These three substances prothrombin or thrombogen, a calcium salt and fibrinogen are always present in the blood. The formation of thrombin which would cause coagulation is prevented by the presence of an anti-thrombin. As soon as blood is shed or tissue are injured a new substance thrombinoplastin is developed which neutralizes the anti-thrombin. This having been accomplished the calcium is enabled to activate the prothrombin with the production of thrombin and hence fibrin (Howell).

Conditions Influencing Coagulation.—The process is *retarded* by cold, retention within living normal vessels, neutral salts in excess, the injection of commercial peptone, etc.

It is *accelerated* by a temperature of 100°F., contact with rough surfaces, the presence of foreign bodies, whipping, etc.

Blood coagulates in the body after the arrest of the circulation in the course of twelve to twenty-four hours; local arrest of the circulation, from compression or a ligature with injury to the lining membrane of the vessel, will cause coagulation, thus preventing hemorrhages from wounded vessels.

Chemic Composition of Plasma.—An average composition of plasma is shown in the following table:

Water		90.00
Proteins	Plasma-albumin	4.50
	Paraglobulin	3.40
	Fibrinogen	0.30
Fatty matters		0.25
Sugar		0.10
Extractives		0.60
Inorganic salts		0.85
		100.00

The water imparts fluidity to the blood and acts as a solvent for the inorganic matters, for sugar, and various products of katabolism.

Plasma-albumin was formerly regarded as the nutritive protein of the blood and directly used as such by the tissue elements. As the amino-acids are now believed to play this rôle, the albumin must have some other function. It may be a reserve supply of protein food.

Paraglobulin is a soft, amorphous substance precipitated by sodium chlorid in excess, or by passing a stream of carbonic acid through dilute serum.

Fibrinogen also can be obtained by *strongly diluting* the serum and passing carbonic acid through it for a long time, when it is precipitated as a viscous deposit.

Fatty matter exists in the blood to the extent of about 0.25 per cent. Just after a meal rich in fat, this amount may be considerably increased. Within a few hours it disappears, though its ultimate fate is unknown.

Sugar is represented by dextrose. The amount present varies from 0.8 to 0.15 per cent. It is derived directly from the glycogen of the liver. Should the normal percentage be increased, the excess will be eliminated by the kidneys and the condition of glycosuria is established.

The *inorganic constituents* are chiefly sodium and potassium chlorids, sulphates and phosphates together with calcium and magnesium phosphates. The sodium chlorid is the most abundant, amounting to about 5.5 parts per thousand. The alkaline salts impart the alkaline reaction and promote the absorption from the tissues of the carbon dioxid.

Excrementitious matters are represented by carbonic acid, urea, creatin, creatinin, urates, oxalates, etc.; they are absorbed from the tissues by the blood and conveyed to the excretory organs, lungs, kidneys, etc.

Gases.—Oxygen, nitrogen, and carbonic acid exist in varying proportions.

The *serum* differs from plasma in not containing those materials which entered into the formation of fibrin.

THE RED CORPUSCLES OR ERYTHROCYTES

The red corpuscles are circular biconcave flattened discs having an average diameter of 0.007 mm. or about $\frac{1}{3,200}$ of an inch. A single corpuscle is of a pale straw color. It is only when aggregated in masses that they assume a red color. In man and mammals the red corpuscles present neither a nucleus nor a cell wall and are universally of a small size, though the size varies considerable in different mammals.

The red corpuscles are exceedingly numerous, amounting to about 5,000,000 in a cubic millimeter of blood. In structure they consist of a firm, elastic, colorless framework—the *stroma*—in the meshes of which is entangled the coloring-matter—the *hemoglobin.*

According to some histologists the red corpuscle, while in the plasma, assumes a bell shape. The circular biconcave shape usually observed under the microscope is regarded as due to cooling and evaporation and concentration of the drawn blood.

In the birds, reptiles, amphibia, and fish the red corpuscles are oval in shape and have a distinct nucleus. They can, therefore, be readily distinguished from the corpuscles of mammals, not only by their structure but also by their size, which is distinctly larger.

Chemic Composition of Red Corpuscles.—When analyzed chemically the red corpuscles are found to consist of water 65 per cent. and solid matter 35 per cent. The solids, moreover, have been found to consist of a pigment hemoglobin 33, protein 0.9, cholesterin and lecithin 0.46, and inorganic salts (chiefly potassium phosphate and chlorid and sodium chlorid) 1.4 per cent. respectively. Of the total solids the hemoglobin constitutes about 94 per cent.

Hemoglobin, the coloring-matter of the corpuscle, is an albuminous compound, composed of C,O,H,N,S, and iron. It may exist in either an amorphous or a crystalline form. When deprived of all its oxygen, except the quantity entering into its intimate composition, the hemoglobin becomes purplish in color, and is known as *reduced hemoglobin.* When exposed to the action of oxygen, it again absorbs a definite amount and becomes scarlet in color, and is known as *oxyhemoglobin.* The amount of oxygen absorbed is 1.34 c.c. for each gram of hemoglobin.

It is this substance which gives the color to the venous and arterial blood. As the venous blood passes through the capillaries of the lungs the *reduced hemoglobin* absorbs the oxygen from the pulmonary air and becomes *oxyhemoglobin,* scarlet in color; the blood becomes arterial. When the arterial blood passes into the systemic capillaries, the oxygen is absorbed by the tissues; the hemoglobin becomes reduced, purple in color, and the blood becomes venous. A dilute solution of oxyhemoglobin gives two absorption bands between the lines D and E of the solar spectrum. Reduced hemoglobin gives but one absorption band, occupying the space existing between the two bands of the oxyhemoglobin spectrum.

The Function of the Red Corpuscles.—The red corpuscles, by virtue of the capacity of their contained hemoglobin for oxygen absorption, may be regarded as carriers of oxygen from the lungs to the tissues, and therefore important factors in the general respiratory process. The size as well as the number of the corpuscles in different classes of animals appears to be directly related to the activity of the respiratory process. In those animals in which the corpuscles are small and numerous and the total superficial area large, respiration is active, the quantity of oxygen absorbed is large, and the energy liberated through oxidation is correspondingly large. In those animals, on the contrary, in which the corpuscles are large and relatively few in number, the reverse conditions obtain. This is in accordance with the fact that the superficial area of any given volume of substance is increased in proportion to the extent to which it is subdivided.

Origin.—The red corpuscles are derived from erythroblasts found in the red marrow of the long bones. In the passages of the capillary network of the marrow, the erythroblasts make their appearance, most probably by a transformation of pre-existing marrow cells which cross the capillary wall from without. At first they are large, homogeneous, colorless, perhaps slightly tinged with hemoglobin and distinctly nucleated. They increase in number by karyokinesis and at the same time increase in their hemoglobin content. In the course of their development the nucleus becomes smaller and denser, when the cells are known as normoblasts. Subsequently the nucleus is extruded, carrying with it a portion of the perinuclear cytoplasm, after which the remainder of the corpuscle assumes the shape and size of the adult corpuscle and is carried out into the general circulation. After severe hemorrahge the formative processes in the marrow may become so active that erythroblasts and normoblasts make their appearance in the blood-stream before the extrusion of the nucleus has taken place.

THE WHITE CORPUSCLES OR LEUKOCYTES

The white corpuscle is grayish in color, round or globular in form though often presenting a more or less irregular surface. Its diameter is about 0.011 mm. or about 1/2,500 of an inch. Some of the white corpuscles are, however, somewhat larger and others smaller.

A typical white corpuscle consists of a ground substance uniformly transparent and apparently homogeneous in which are embedded a number of granules of varying size, some of which are very fine, while others are large. By various reagents it has been demonstrated that the granules are fatty, protein, and carbohydrate (glycogen) in character. In the fresh cells the existence of a nucleus is difficult of detection, though its presence can be demonstrated by the addition of acetic acid, which renders the perinuclear cytoplasm more transparent and makes the nucleus conspicuous and sharply defined.

The number of white corpuscles per cubic millimeter of blood is much less than the number of red corpuscles, the ratio being in the neighborhood of 1 white to 700 red. This ratio, however, varies within wide limits in different portions of the body and under normal variations in physiologic conditions. In the blood of the splenic artery there is but 1 white to 2,260 red, while in the splenic vein there is 1 white to every 60 red; or about thirty-eight times as many as in the artery. In the portal vein there is 1 white to 740 red, while in the hepatic vein there is 1 white to 170 red.

The total number of white corpuscles per cubic millimeter has been estimated at from 5,000 to 10,000, though the average is about 7,500. The number, however, is influenced by a variety of physiologic conditions.

The white corpuscles are usually divided into

1. Lymphocytes	Small	25 per cent.
	Large	4 to 8 per cent.
2. Leukocytes	Polymorphonuclear	60 to 70 per cent.
	Eosinophiles	0.5 to 2 per cent.

In abnormal conditions of the blood other forms of leukocytes are frequently present, *e.g.*, myelocytes, leukoblasts, myeloplaxes, etc., the significance of which is not always apparent.

Properties.—The white corpuscles possess the power of spontaneous movement, alternately contracting and expanding, throwing out processes of their substance and quickly withdrawing them, thus changing their shape from moment to moment. These movements resemble those of the ameba, and for this reason are termed *ameboid*. The white corpuscles also possess the capability of passing through the walls of the capillaries into the surrounding tissue spaces; to this process the term *diapedesis* is given.

Functions.—The functions of the white corpuscles are but imperfectly known, and at present no positive statements can be made. It has been suggested that wherever found in the body, whether in blood or tissues, they are engaged in the removal of more or less insoluble particles of disintegrated tissues, in attacking and destroying more or less effectively various forms of invading bacteria and thus protecting the body against their deleterious activity. This they do by surrounding, enveloping, and incorporating either the tissue particle or bacterium and digesting it. On account of this swallowing action these cells were termed by Metchnikoff *phagocytes* and the process *phagocytosis*. The cells engaged in this process are the polymorphonuclear leukocytes and the large and the small lymphocytes. He regards them as the general scavengers of the body. It has been suggested that they are also engaged in the absorption of fat from the lymphoid tissue of the intestine. In their dissolution they contribute to the blood-plasma certain protein materials which assist under favorable circumstances in the coagulation of the blood.

Origin.—The first group of the white corpuscles—lymphocytes—take their origin entirely from the lymph-adenoid tissues of the body, *e.g.*, the lymph-glands, solitary and agminated follicles of the intestines, etc. As the lymph flows through these structures the lymph-corpuscles, as the future lymphocytes of the blood are called in these situations, are washed out and carried by way of the lymph-stream into the general circulation.

The second group—the polymorphonuclear, the eosinophiles and basophile leukocytes have their origin in the bone marrow. The immediate ancestors of these cells are known as myelocytes and are normally found in the red bone-marrow. These cells, through transitional stages, assume the characteristics of the leukocytes just mentioned and pass directly into the capillaries of the marrow whence they are distributed throughout the body.

After an unknown period of life the leukocytes undergo dissolution and disappear.

Blood Platelets.—These are small histologic elements circulating in the blood though their presence can not be readily determined except under special conditions. They are colorless homogeneous or finely granular non-nucleated disks which vary in diameter from 1.5 to 3 5 micro-millimeters. They number from 250,000 to 300,000 per cubic millimeter of blood. They are supposed to represent fragments of the cystoplasm of giant cells found in the marrow of bones. They are believed to be connected in some way with the coagulation of the blood.

THE CIRCULATION OF THE BLOOD

The circulatory apparatus by which the blood is distributed to and removed from all regions of the body consists of a central organ, the heart; a series of branching diverging tubes, the arteries; a network of minute passageways with extremely delicate walls, the capillaries; a series of converging tubes, the veins. These structures are so arranged as to form a closed system of vessels within which the blood is kept in continuous movement mainly by the pressure produced by the pumping action of the heart, though aided by other forces. By reason of its general arrangement and activity the tissues are continuously supplied with nutritive materials and freed from their waste materials and carried to the eliminating organs.

The Heart.—The heart is a conic or pyramid-shaped hollow muscle situated in the thorax just behind the sternum. The base is directed upward and to the right side; the apex downward and to the left side, extending as far as the space between the cartilages of the fifth and sixth ribs. In this situation the heart is enclosed and suspended in a fibro-serous sac, the *pericardium*, attached to the great vessels at its base.

Cavities of the Heart.—The general cavity of the heart is subdivided by a longitudinal septum into a right and left half; each of these cavities is in turn subdivided by a transverse septum into two smaller cavities, which communicate with each other and are known as the auricles and ventricles; the orifice between the auricle and ventricle being known as the *auriculo-ventricular orifice*. The heart ,therefore, consists of four cavities—a right auricle and ventricle and a left auricle and ventricle.

The right auricle and the right ventricle constitute the *venous* heart; the left auricle and left ventricle constitute the *arterial* heart.

Into the right auricle the two terminal trunks of the venous system—the *superior and inferior vena cava*—empty the venous blood which has been collected from all parts of the system; from the right ventricle arises the *pulmonic artery*, which, passing into the lungs, distributes the blood to the walls of the air-cells of the lungs; into the left auricle empty four *pulmonic veins*, which have collected the blood from the lung capillaries; from the left ventricle springs the *aorta*, the general trunk of the arterial system, the branches of which distribute the blood to the entire system.

The Course of the Blood through the Heart.—Reference to Fig. 11 will make it clear that there is a pathway for the blood between the venæ cavæ on the right side and the aorta on the left side by way of the right side of the heart, the cardio-pulmonic vessels and the left side of the heart.

The venous blood flowing toward the heart is emptied by the superior and inferior vena cava into the right auricle from which it passes through the auriculoventricular opening into the right ventricle; thence into and through the pulmonic artery and its branches to the pulmonic capillaries where it is arterialized, *i.e.*, yields up a portion of its carbon dioxid and takes on a fresh supply of oxygen—and is changed in color from bluish red to scarlet red. The arterialized blood flowing toward the heart is emptied by the pulmonic veins into the left auricle from which it passes through the auriculoventricular opening into the left ventricle; thence into the aorta and its branches to the systemic capillaries where it is dearterialized by an opposite exchange of gases, *i.e.*, yields up a portion of its oxygen to, and absorbs

FIG. 11.—DIAGRAM OF THE CIRCULATION.

1 1. Heart. 2. Lungs. 3. Head and upper extremities. 4. Spleen. 5. Intestines. 6. Kidney. 7. Lower extremities. 8. Liver. —(*After Dalton.*)

carbon dioxid from the tissues, and changes in color, from scarlet red to bluish red. The venous blood is again returned to the systemic veins to the venæ cavæ.

Though the blood is thus described as flowing first through the right side and then through the left side, it must be kept in mind that the two sides fill synchronously; that while the blood is flowing into the right side from the venæ cavæ, it is also flowing into the left side from the pulmonic veins in equal quantities and velocities.

While there is but one circulation, physiologists frequently divide the circulatory apparatus into:

1. The *systemic circulation*, which includes the movement of the blood from the left side of the heart through the aorta and its branches, through the capillaries and veins, to the right side of the heart.

2. The *pulmonic circulation*, which includes the course of the blood from the right side through the pulmonic artery, through the capillaries of the lungs and pulmonic veins, to the left side of the heart.

3. The *portal circulation*, which includes the portal vein. This vein is formed by the union of the radicles of the gastric, mesenteric, and splenic veins, and carries the blood directly into the liver, where the vein divides into a fine capillary plexus, from which the hepatic veins arise; these empty into the ascending vena cava.

Orifices and Valves.—The movement of the blood along the path of the circle above outlined is accomplished by the alternate *contraction* and *relaxation* of the muscle walls of the heart. That the movement may be a progressive one, that there shall be no regurgitation during either the contraction or the relaxation, it is essential that some of the orifices of the heart be closed during each of these periods. This is accomplished by the heart valves.

The valves of the heart are formed by a reduplication of the endocardium strengthened by connective tissue.

The right auriculo-ventricular opening is provided with a valve consisting of three portions of cusps which during the period of relaxation are directed into the ventricle; during the contraction they are raised and placed in complete apposition when they act as a valve preventing a backward flow into the auricle. For this reason it is known as the *tricuspid* valve. The left auriculo-ventricular orifice is provided with a valve consisting of but two cusps and is, therefore, termed the *bicuspid* valve, or, from its fancied resemblance to a bishop's miter, the *mitral* valve. The mode of action of this valve is similar in all respects to the tricuspid valve. To the undersurface and to the edges of these valves the *tendinous* cords of the *papillary muscles* are firmly and intricately attached. These cords are just sufficiently long to permit closure of the valves and to prevent them from being floated into the auricle.

The orifice of the pulmonic artery is provided with three semilunar or pocket-shaped membranes, the *semilunar* valves. The orifice of the aorta is also provided with three similarly arranged semilunar membranes, the *semilunar valves.*

During the period of *relaxation* of the heart the edges of the semilunar valves are in close apposition and prevent a return of the blood into the ventricles; during the contraction they are directed into the pulmonic artery and aorta. In the former position they are shut; in the latter, they are open.

The Auriculo-ventricular Bundle.—This is a specialized bundle of muscle-fibers discovered in part by His and in part by Tawara which unites anatomically and physiologically the right auricle with the ventricles. The reason for the existence of this bundle lies in the fact that the muscle fibers of the auricles and ventricles are completely separated by the transverse fibrous septum to which they are attached. The origin, course and distribution of this bundle is as follows:

It arises near the opening of the coronary sinus where it is connected with the true auricular fibers. From their origin the fibers converge to form a distinct bundle which then passes forward on the right side of the auricular septum between the lower edge of the fossa ovalis and the auriculo-ventricular septum; just above the insertion of the median cusp of the tricuspid valve the bundle presents a very complicated network of muscle-fibers which has been designated as a knot or the auriculo-ventricular node or the node of Tawara; from the anterior portion of the node a bundle of fibers turns downward and penetrates the auriculo-ventricular septum, beyond which it passes below the *pars membranacea septi* to the upper limit of the muscle portion of the ventricular septum. It then divides into two limbs or branches which descend on either side of the septum under the endocardium, the right limb lying somewhat deeper than the left. Each of these limbs is enclosed by a layer of connective tissue which isolates it from the musculature of the ventricular septum as far as the lower third of the ventricular cavities. In this region they divide into a number of bundles, some of which enter the papillary muscles, while others, forming tendon-like strands, branch freely beneath the endocardium and spread in all directions over the entire inner surface of the ventricle and enter into histologic connection with the true cardiac muscle-fibers. The ultimate terminations of this system beneath the endocardium constitutes the so-called Purkinje-fiber layer. From its function this bundle has been termed the conduction system of the heart—the conduction of an excitation process from the auricle to the ventricles.

The Sino-auricular Node or the Keith-Flack Node.—This is a small mass of primitive muscle tissue situated in the sulcus terminalis at the junction of the superior vena cava and the auricular appendix. It is supplied with blood-vessels and nerves. From the node muscle-fibers pass along the sulcus for a distance of two centimeters and finally becomes connected with the true auricular fibers. Experimental investigations lead to the inference that it is directly concerned in the initiation of the heart beat. It has been designated the "pace-maker" of the heart.

The Mechanics of the Heart.—With each beat, the heart presents two distinct movements which alternate with each other in quick succession. One is the movement of contraction, or the systole, by which the blood contained within its cavities is ejected into the arteries—pulmonic artery and aorta; the other is the movement of relaxation, or the diastole, followed by a pause during which the cavities again fill up with blood from the venæ cavæ and pulmonic veins.

The contraction of any part of the heart is termed the *systole;* the relaxation, the *diastole.* As each side of the heart has two cavities the walls of which contract and relax in succession, it is customary to speak of an auricular systole and diastole, and a ventricular systole and diastole. As the two sides of the heart are in the same anatomic relation to each other, they contract and relax in the same periods of time.

The immediate cause of the movement of the blood through the vessels is the contraction and relaxation of the muscle-walls of the heart, and more particularly of the walls of the ventricles, each of which plays alternately the part of a force-pump, and possibly to a slight extent of a suction-pump. The motive power is furnished by the heart itself, by the transformation of potential energy, stored up during the period of rest, into kinetic energy —*i.e.*, heat and mechanic motion.

The Cardiac Impulse.—In passing from the diastolic to the systolic condition the transverse diameter diminishes while the antero-posterior diameter increases, and the whole heart becomes somewhat more conic in shape. It is questionable if the vertical diameter perceptibly shortens. During the systole the heart hardens, increases in convexity, and is more forcibly pressed against the chest wall. As this takes place suddenly, it gives rise to a marked vibration of the chest wall, known as the cardiac impulse.

This impulse is principally observed in the space between the fifth and sixth ribs about an inch internal to a line drawn vertically from the middle of the clavicle. The cardiac impulse is synchronous with the cardiac systole.

The Cardiac Cycle.—The term cardiac cycle is employed to express the sequence of events from the beginning of one auricular systole and the beginning of the auricular systole which immediately follows it. An examination of the heart shows that each pulsation may be divided into three phases, viz.:

1. The auricular systole.
2. The ventricular systole.
3. The pause or period of repose during which both auricles and ventricles are at rest.

The duration of a cycle, as well as the duration of its three stages, varies in different animals in accordance with the number of cycles which recur in a minute. In human beings in adult life there are about 72 cycles to the minute; the average duration is, therefore, 0.80 sec. From this it follows that the time occupied by any one of the three stages must be extremely short and difficult of determination. From experiments on animals and from observations made on human beings, the following estimates have been made and accepted as approximately correct for human beings:

1. The auricular systole—0.16 sec.; the auricular diastole, 0.64 sec.
2. The ventricular systole—0.32 sec.; the ventricular diastole, 0.48 sec.
3. The period of rest for both auricles and ventricles—0.32 sec.

The Movement of the Blood during the Cycle.—It is apparent that with the relaxation of the auricular walls blood at once flows from the vanæ cavæ and the pulmonic veins into the auricular cavities and continues so to do throughout the entire auricular diastole. With the relaxation of the ventricular walls, however, the blood that has accumulated in the auricles up to this time, or its equivalent coming from the venæ cavæ and pulmonic veins, now flows into the ventricles until they are nearly filled. Before they are filled, however, the auricular diastole comes to an end, the auricular walls again contract and force some of their contained blood into the ventricles and thus rapidly complete the filling. The ventricular systole immediately follows, during which the blood is driven into the pulmonic artery and aorta. This having been accomplished, the ventricles relax, and the blood that has been accumulating in the auricles begins to flow into the ventricles, after which the same series of events follows as in the previous cycle.

The Action of the Valves.—The forward movement of the blood is permitted and regurgitation prevented by the alternate action of the auriculo-ventricular and semilunar valves. As a point of departure for a consideration of the action of these valves and their relation to the systole and diastole of the heart, the close of the ventricular systole may be selected. At this moment, the semilunar valves, which during the systole, are directed outward by the blood current are now suddenly and completely closed by the pressure of the blood in the aorta and pulmonic artery. Regurgitation into the ventricles is thus prevented.

During the ventricular systole, the relaxed auricles are filling with blood. With the ventricular diastole this blood or its equivalent flows into the relaxed and easily distensible ventricles until both auricles and ventricles are nearly filled. The tricuspid and mitral valves which are hanging down into the ventricular cavities, are now floated up by currents of blood welling up behind them until they are nearly closed. The auricles now suddenly contract, forcing their contained volumes into the ventricles which become fully distended.

With the cessation of the auricular systole, the ventricular systole begins. If the blood is not to be returned to the auricles the tricuspid and mitral valves must be instantly and completely closed. This is accomplished by the upward pressure of the blood which brings their free edges in close apposition. Reversal in the position of these valves is prevented by the contraction of the papillary muscles which exert a traction on their undersurfaces and edges and hold them steady.

The blood now confined in the ventricles between the closed auriculo-ventricular and semilunar valves is subjected to pressure on all sides; as the pressure rises proportionately to the vigor of the contraction there comes a moment when the *intra-ventricular pressure* exceeds that in the aorta and pulmonic artery; at once the semilunar valves are thrown open and the blood discharged. Both contraction and outflow continue until the ventricles are practically empty, when relaxation sets in attended by a rapid fall of pressure. Under the influence of the positive pressure of the blood in the aorta and pulmonic artery, the semilunar valves are again closed. The accumulation of blood in the auricles, attended by a rise in pressure, again forces the tricuspid and mitral valves open. With these events the cardiac cycle is completed.

Sounds of the Heart.—If the ear be placed over the cardiac region, two distinct sounds are heard during each revolution of the heart, closely following each other, and which differ in character.

The sound coinciding with the systole in point of time—the *first sound*—is prolonged and dull, and caused by the closure and vibration of the auriculo-ventricular valves, the contraction of the walls of the ventricles, and the apex-beat; the *second sound*, occurring at the beginning of the diastole, with the second phase of the cardiac cycle is short and sharp, and caused by the closure and vibration of the semilunar valves.

The Intra-ventricular Pressures.—By this term is meant the pressure that arises in the ventricles during the time of the systole. The reason for this rise of pressure arises from the fact that the semilunar valves are kept tightly shut by the pressure of the blood in the aorta and pulmonic artery. With the beginning of the systole the auriculo-ventricular valves are suddenly closed and now the blood is imprisoned. If the semilunar valves are to be opened and the blood discharged the intra-ventricular pressure must exceed the pressure in the aorta and pulmonic artery. Moreover as the aortic and pulmonic pressures increase with the discharge of blood the intra-ventricular pressure must continue to rise and exceed the increased pressure in these vessels. This the heart does by calling on the reserve power with which it is endowed. Should it fail to meet some sudden rise of pressure in the aorta it would remain in a condition of permanent diastole.

The Frequency of the Heart-beat.—The frequency of the heart-beat varies with a variety of conditions: *e.g.*, age, sex, posture, exercise, etc.

Age.—The most important normal condition which modifies the activity of the heart is age. Thus:

Before birth, the number of beats a minute averages..........	140
During the first year it diminishes to	128
During the third year it diminishes to..........................	95
From the eighth to the fourteenth year it averages.............	84
In adult males it averages	72

Sex.—The heart-beat is more rapid in females than in males. Thus while the average beat in males is 72, in females it is usually 8 or 10 beats more.

Posture.—Independent of muscle efforts the rate of the beat is influenced by posture. It has been found that when the body is changed from the lying to the sitting and to the standing position, the beat will vary as follows—from 66 to 71 to 81 on the average.

Exercise and *digestion* also temporarily increase the number of beats.

A rise in blood-pressure from any cause whatever is usually attended by a decrease, while a *fall* in blood-pressure is attended by an increase in the rate.

The Blood Supply to the Heart.—The nutrition of the heart, its contractility, the force and frequency of the beat are dependent on and maintained by the introduction of arterialized blood into and the removal of waste products from its tissue. This is accomplished by the coronary arteries and the coronary veins. The arteries and veins on the surface of the heart are known as the extra-mural arteries and veins; those which are found in the substance of the heart are known as intra-mural arteries and veins. During the time of the systole the intra-mural branches are compressed and the blood flow into the heart walls interrupted, though at the same time the extra-mural arteries are filled with blood from the aorta; during the time of the diastole, the recoil of these latter vessels forces the blood into the intra-mural arteries and capillaries, thus furnishing to the muscle cells an additional supply of nutritive materials and receiving products of waste; at the succeeding systole the venous blood is driven from the intra-mural into the extra-mural veins and so into the right auricle.

The Causation of the Heart-beat.—From the fact that the heart will continue to beat for a variable length of time after removal from the body (the time varying with the species of animal from which it has been obtained) it is evident that the beat is independent of the central nerve system.

The fundamental condition for the continuance of the beat is the maintenance of the irritability. So long as this persists the heart will respond to its appropriate stimulus. The irritability of the heart within the body is dependent on the supply of blood coming through its nutrient vessels or flowing through its cavities. Outside the body, the irritability can be maintained for some hours by perfusing the coronary system of vessels with the Ringer-Locke solution.

The Nature of the Stimulus.—The presence of nerve-cells in the walls of the heart, their relation to the muscle cells, the pronounced activity of the sinus of the frog heart where they are very abundant; the feeble activity of the apex where they are absent gave rise to the idea that the stimulus is a nerve impulse rhythmically and automatically discharged by these nerve-cells. This view is no longer entertained. It has been demonstrated that portions of the heart muscle, that do not contain nerve-cells, will continue to exhibit rhythmic contraction for some hours if supplied with oxygenated and defibrinated blood; that the embryonic heart contracts rhythmically before nerve-cells have migrated to its walls.

The stimulus therefore evidently arises within the heart muscle. In other words, it is *myogenic* and not *neurogenic*. The stimulus is now believed to be chemic in character and due to a reaction between the inorganic salts in the muscle cells and those in lymph by which they are surrounded.

The Sequence of Sinus, Auricular and Ventricular Contraction.—An examination of the heart of the frog shows that each cycle begins with a contraction of the sinus venosus followed by a contraction of the auricle, then by a contraction of the ventricle. Between each event there is a definite pause the result of an interference with the passage of the excitation process (this being the cause for the contraction) across the junction of these cavities formed by dense connective tissue. The difficulty of passage may be increased by ligation of the sino-auricular junction, after which the auricles or ventricles come to rest though the sinus beats at the usual rate. The auriculo-ventricular junction may also be ligated after which the ventricle comes to rest though the sinus and auricles beat as usual. The physiologic stimulus apparently arises and acts in the walls of the sinus.

In the mammal the visible cycle begins by a contraction of the auricle followed by that of the ventricle. Between these two events there is also a definite pause, but for a somewhat different reason. In the mammal heart the cycle begins in the muscle tissue composing the node of Keith, the so-called pace-maker. The excitation process set free passes to the auricular muscle and calls forth a contraction. Owing to the fact that there is no continuity of muscle fibers across the junction, there has been developed the auriculo-ventricular bundle previously described, which has for its function the reception, at its auricular extremity, of the excitation process and transmitting it to the ventricle which at once contracts in response to its stimulating effect. The time required for the passage of the excitation from auricle to ventricle is about 0.2 sec. and is known as the a–c or the as–vs interval.

The function of the auriculo-ventricular bundle may be shown by its compression by a suitable clamp or transverse section in the heart of a mammal. If this be done quickly the ventricle at once ceases to beat, though the auricles beat at their accustomed rate. After a variable period from 30 to 70 seconds, the ventricular beat returns but at a much slower rate, usually about one-third the auricular rate. The cause of this contraction is attributed to the continuous action of the inorganic salt, in the blood.

If the auriculo-ventricular bundle be destroyed by a pathologic process in that portion just above the bifurcation at the top of the ventricular septum (the bundle of His) the ventricle at once ceases to beat; but after the usual period of time it again begins to beat, but at a slower rate. This is the underlying cause of the group of symptoms known as the Adams-Stokes syndrome. The auricular beats as indicated by the pulsations of the jugular veins may be 80 and the ventricular beats as indicated by the pulse from 22 to 30.

The Influence of the Central Nerve System on the Action of the Heart.—Though the heart-beat is independent of the central nerve system, it is to a considerable extent modified by it either in the way of *acceleration* or *inhibition.* In all classes of animals the heart not only contains localized collections of nerve-cells, but it is also connected with the central nerve systems by two sets of nerve-fibers.

In the frog heart a group of nerve-cells is found in the sinus at its junction with the auricle, and known as the crescent or ganglion of Remak; a second group is found at the base of the ventricle on its anterior aspect and known as the ganglion of Bidder; a third group is found in the auricular septum, known as the septal ganglion, or the ganglion of Ludwig.

In the dog and the mammalian heart generally, the nerve-cells though present are not arranged in such definite groups, but are distributed in the terminations of the venæ cavæ, pulmonic veins, the walls of the auricles and in the neighborhood of the base of the ventricles.

These cells were formerly regarded as the source of the stimuli for the excitation and regulation of the heart's contraction. This view is no longer entertained.

The extra cardiac nerves, those which connect the heart with the central nerve system, are the sympathetic and the vagus. Experiments have demonstrated that the sympathetic is the motor nerve to the heart, the nerve that accelerates the rate and augments the force of the beat, while the vagus is the inhibitor nerve, the nerve that inhibits or controls the rate and force of the beat.

Since the heart muscle belongs to the autonomic tissues, it follows that the accelerator and the inhibitor nerve pathways consist of two consecutively arranged neurones. The first is termed preganglionic, the second postganglionic.

The Sympathetic.—The preganglionic fibers have their origin in the medulla oblongata and very probably from nerve-cells in the gray matter beneath the floor of the fourth ventricle. From this origin they descend the spinal cord as far as the level of the second, third, and at times the fourth thoracic nerves. At this level they emerge from the cord in company with the nerve-fibers composing the anterior roots of the second, third, and fourth thoracic nerves. After a short course, they enter the white rami communicantes, then the sympathetic chain and pass upward to the ganglion stellatum (the first thoracic), and to the inferior cervical ganglion as well, around the nerve-cells of both of which their terminal branches arborize. From the nerve-cells of both the stellate and inferior cervical ganglia, the postganglionic fibers arise, that is, the sympathetic nerves proper, which after emerging from the ganglia pass toward the heart. On reaching the heart they terminate directly in the muscle-cell, or indirectly through the intermediation of intra-cardiac nerve-cells. The former mode of termination is the more probable.

Stimulation of these fibers in any part of their course, more readily the sympathetic fibers after their emergence from the ganglia, is followed by an increase in the rate and sometimes by an increase in the force of the heart-beat. For this reason the sympathetic is said to exert an accelerator and an augmentor influence on the heart-beat.

The percentage increase in the acceleration varies in different animals. In some instances the increase varies from 58 per cent. to 100 per cent. If the heart is beating slowly before stimulation, the acceleration is more marked than if it is beating rapidly.

Division of the sympathetic nerves is at once followed by a diminution in the rate, the degree of which will depend to some extent on the rate at which the heart was beating prior to the division. The results, therefore, that follow stimulation and division of these nerves indicate that they are transmitting nerve impulses from the centers from which they arise to the heart, upon which they exert a stimulating influence on the rate and force of the beat.

The group of cells from which the accelerator fibers arise is known as the *cardio-accelerator* center. It is believed to be in a state of continuous or tonic activity.

The Vagus.—The preganglionic fibers have their origin in a group of nerve-cells situated beneath the floor of the fourth ventricle. From this origin they pass out in the trunk of the vagus proper. In the neighborhood of the inferior laryngeal nerves, branches containing efferent fibers are given off which pass to the heart. Their terminal branches arborize around the intra-cardiac ganglia. From the cells of the ganglia the post-ganglionic fibers arise which terminate directly in some of the heart muscle fibers.

Stimulation of the vagus fibers in any part of their course with induced electric currents will cause the heart to come to a standstill almost immediately in the condition of diastole, and may be so kept for a variable period, from fifteen to thirty seconds or more, during which its walls are relaxed and its cavities filled with blood. On cessation of the stimulation the contractions return and in a very short time the former rate and force of the beat are regained. If the electric currents are of feeble strength, the heart will come to rest gradually, through a gradual diminution in the rate and force of the contraction. During the period of inhibition the walls are completely relaxed and the cavities filled with blood.

Division of one vagus is followed in some mammals, *e.g.*, dog by a marked increase in the rate of beat and if both vagi are divided the increase may amount to from 50 to 75 per cent. The results of stimulation and division of the vagus nerves indicate that they are continuously transmitting nerve impulses from the centers from which they arise, to the heart muscle, on the activity of which they exert a restraining or inhibitor influence.

The center in the medulla from which the inhibitor fibers arise is known as the *cardio-inhibitor* center. This center is also believed to be in a state of continuous activity though capable of being increased or decreased in activity by transmitted nerve impulses from various regions of the body.

Reflex acceleration or *inhibition* of the heart is caused by nerve impulses transmitted to the cardio-inhibitor center alone, through afferent nerve-fibers, some of which are *inhibitor*, while others are *excitator*. In the first instance the center is inhibited in its action whereupon the cardio-accelerator center has a freer action and the heart rate is accordingly accelerated; in the second instance the center is excited to increased activity and its inhibitor effect increased. The effects of the cardio-accelerator center is thus in part annulled and the heart rates is diminished.

THE VASCULAR APPARATUS

The vascular apparatus in its entirely consists of a closed system of vessels which not only contain the blood, but under the driving power of the heart, transmit it to and from all regions of the body. It is usually divided into a systemic and a pulmonic portion.

The Systemic Vascular Apparatus.—This portion of the general vascular apparatus includes all the vessels extending from the left ventricle to the right auricle: viz., the arteries, capillaries, and veins. Though serving as a whole to transmit blood from the one side of the heart to the other, each one of these three divisions has separate but related functions, which are dependent partly on differences in structure and physiologic properties, and partly on their relation to the heart and its physiologic activities.

The Arteries.—The arteries serve to transmit the blood ejected from the heart to the capillaries; that this may be accomplished they divide and subdivide and ultimately penetrate each and every area of the body. Their repeated division is attended by a diminution in size, a decrease in the thickness and a change in the structure of their walls.

A typical artery consists of three coats: an internal, the *tunica intima,* a middle, the *tunica media;* an external, the *tunica adventitia.*

The internal coat consists of a structureless elastic basement membrane, the inner surface of which is covered by a layer of elongated spindle-shaped endothelial cells. The middle coat consists of several layers of circularly arranged, non-striated muscle-fibers, between which are networks of elastic fibers. The external coat consists of bundles of connective tissue of the white fibrous and yellow elastic varieties. Between the external and middle coats there is an additional elastic membrane. In the small arteries there is but a single layer of muscle-fibers. In the large arteries the elastic tissue is very abundant, exceeding largely in amount the muscle tissue. It is also more closely and compactly arranged. The external coat is well developed in the large arteries.

The presence in their walls of both elastic and contractile elements, endows the arteries with the two properties of elasticity and contractility.

Elasticity.—The elasticity is best developed in the large arteries, though it is also present in arteries of relatively small size. By virtue of the elasticity, the arteries are capable of being distended and elongated and when the distending force is removed of recoiling or retracting and returning to their former condition. The arteries are thus enabled to adapt themselves to the variations in the volume of blood discharged from the ventricle at a single beat or in a unit of time. The elasticity also converts the intermittent movement of the blood imparted to it by the heart as it is ejected from the ventricle, into a remittent movement in the arteries and finally into the continuous and equable movement observed in the capillaries.

Contractility.—The contractility, especially of the small arteries, permits of a variation in the amount of blood passing into a given capillary area in a unit of time. During the functional activity of any organ or tissue there is need for an increase in the amount of blood beyond that supplied during functional inactivity or rest. This is accomplished by a relaxation of the muscle-fibers. With the cessation of activity the muscle-fibers again contract and reduce the amount of blood to that required for nutritive purposes only. The tonic contraction of the arteriole muscle-fibers increases considerably the resistance to the outflow of blood into the capillaries. They thus assist in maintaining the blood-pressure in the arteries. This resistance is generally termed the *peripheral resistance* though there is included under this term the resistance offered by the small caliber of the capillary blood-vessel as well. This latter factor is constant, the former variable.

The Capillaries.—The capillaries are small vessels continuous with the arteries on the one hand and with the veins on the other hand. Though different in structure from a small artery or vein, there is no sharp boundary between them, as their structures pass imperceptibly one into the other. A true capillary, however, is of uniform size in any given tissue and does not undergo any noticeable decrease in size from repeated branchings. The diameter varies in different tissues from 0.0045 mm. to 0.0075 mm., just sufficiently large to permit the easy passage of a single red corpuscle. The length varies from 0.5 mm. to 1 mm. The wall of the capillary is composed of a single layer of nucleated endothelial cells with serrated edges united by a cementing material. Though extremely short, the capillaries divide and subdivide a number of times, forming meshes or networks, the closeness and general arrangement of which vary in different localities.

As the endothelial cells are living structures and characterized by irritability, contractility and tonicity, it may be assumed that the capillary wall as a whole is characterized by the same properties. Upon the possession of these properties the functions of the capillary depend.

The *function* of the capillary vessel is to permit of a passage of the nutri tive materials of the blood into the surrounding tissue spaces and of waste products from the tissue spaces into the blood. The structure of the capillary wall is well adapted for this purpose. Composed as it is of but a single layer of endothelial cells, the thickness of which defies accurate measurement, it readily permits, under certain conditions, of the necessary exchange of materials between the blood and the tissues. The forces which are concerned in the passage of materials across the capillary wall are embraced under the terms *diffusion*, *osmosis*, and *filtration*. As a result of the interchange of materials the tissues are provided with nutritive materials and relieved of the presence of the products of metabolism. .As the blood loses oxygen and gains carbon dioxid, it changes in color from a scarlet red to a bluish red. In consequence of the exchange of materials, the blood undergoes a change in composition, the extent and character of which varies in accordance with the activities and character of the organ traversed by it.

In order that the nutritive materials may pass across the capillary wall in amounts sufficient to maintain the necessary supply of lymph in the lymph or tissue spaces, it is essential that the blood shall flow into and out of the capillary vessels constantly and equably, in volumes varying with the activities of the tissues, under a given pressure and with a definite velocity. The conditions are made possible by the coöperation of the physical properties and actions of the heart and vascular apparatus.

The Veins.—The veins arise from the distal side of the capillary vessels. As they emerge they are quite small and designated venules. By their convergence and union the veins gradually increase in size in passing from the periphery toward the heart. Their walls at the same time correspondingly increase in thickness. The veins from the lower extremities, the trunk, and abdominal organs finally terminate in the inferior vena cava. The veins from the head and upper extremities terminate in the superior vena cava. Both venæ cavæ empty into the right auricle.

The veins consist of three coats, an internal, a middle and an external similar in their composition to most of the arteries. The elastic and muscular tissues are, however, not so abundant.

Veins are distinguished by the possession of valves throughout their course, which are arranged in pairs, and formed by a reflection of the internal coat, strengthened by fibrous tissues; they always look toward the heart, and when closed prevent a reflux of blood in the veins. Valves are most numerous in the veins of the extremities, but are entirely absent in many others.

The Flow of the Blood through the Vessels.—During the flow of the blood through the arteries, capillaries and veins, certain phenomena are presented by each of these three divisions of the vascular apparatus. These are mainly *velocity* and *pressure*, and in the arteries alone an alternate expansion and recoil of the arterial wall with each heart-beat, termed the *pulse*.

Blood-pressure.—Blood-pressure may be defined as the pressure exerted radially or laterally by the moving blood stream against the sides of the vessels. This pressure is the result of (1) the driving power of the heart, and (2) of the resistance offered to the forward movement of the blood—a resistance due to the cohesion and friction of the molecules of the blood, of the blood corpuscles, and the adhesion of the blood to the sides of the blood-vessels. That there is such a pressure within the arteries, capillaries, and veins, different in amount in each of these three divisions of the vascular apparatus, is evident from the results which follow division of an artery or a vein of corresponding size. When an artery is divided, the blood spurts from the opening for a considerable distance and with a certain velocity. The reason for this lies in the fact that the vessel has been distended by the pressure from within and its walls thrown into a condition of elastic tension, so that at the moment there is an outlet, the vessel suddenly recoils and forces the blood out with a velocity and to a height proportional to the distention. When a vein is divided, the blood as a rule merely wells out of the opening with but slight momentum, and for the reason that the vessel has been but slightly, if at all distended by the pressure. These results indicate that the blood in the arteries stands under a pressure considerably higher than that of the atmosphere, while that in the veins stands under a pressure perhaps but slightly above that of the atmosphere. Especially true is this of the larger veins.

Experimentally it has been determined that the pressure in the arteries at the end of the cardiac diastole approximates in man about 90 mm. Hg: and is termed the *diastolic* pressure. During the systole and with the discharge of blood into the aorta the pressure rises from 30 to 40 mm. higher which is then termed the *systolic* pressure. The pressure in the capillaries approximates 20 to 40 mm. and in the veins from 20 to 0 mm. or even less at the terminations of the venæ cavæ.

The difference in the height of the pressure in the venous system as contrasted with the arterial system is due to the progressive diminution of the resistance from the beginning of the aorta to the ends of the venæ cavæ, together with the small diameter of the capillaries, increased to a variable extent, by the tonic contraction of the arteriole muscle.

The Causes of the Blood-pressure.—*The Heart.*—The primary factor in the production of the pressure is the pumping action of the heart. Should there be any cessation in its activity, the elastic walls of the arteries would recoil and force the blood into the veins. There would be coincidently a fall of the pressure to that of the atmosphere. Even under normal circumstances this condition is approximated during the diastole. The recoil of the arterial wall by which the forward movement of the blood is maintained is attended by a fall in pressure. But before this reaches any considerable extent, the heart again contracts and forces its contained volume of blood into the arteries.

The Resistance.—The secondary factor is the resistance to the flow of blood through the vessels, the nature of which has been previously stated. So long as the resistance, and especially that variable element of it at the periphery of the arterial system, viz., the tonic contraction of the arteriole muscle maintains a certain average value, so long will the pressure in each division of the vascular apparatus maintain an average or a physiologic value. Should the resistance at the periphery of the arterial system vary in either direction, the result of an increase or a decrease in the degree of the contraction of the arteriole muscle, there will arise a change in the relative degree of pressure in each of the three divisions of the vascular apparatus.

The Elasticity of the Vessel Walls.—A tertiary factor is the elasticity of the arterial wall. While it can hardly be said that the elasticity is a cause of the pressure, there can be attributed to it the capability of modifying and assisting in the maintenance of the pressure at a more or less constant level; for were it not for this property of the vessel wall the variations in pressure during and after the systole would be far more extensive than they are, and would approximate the variations observed in tubes with rigid walls. The elasticity, moreover, assists in the equalization of the blood stream, converting the intermittent and remittent flow characteristic of the large arteries into the continuous equable stream characteristic of the capillaries. It also permits of wide variations in the amount of blood the arteries can contain between their minimum and maximum distention.

Variations in the Arterial Pressure.—From the preceding statements it is apparent that the existing arterial pressure may be increased by:

1. An *increase* in the rate or force of the heart's contraction.
2. An *increase* in the peripheral resistance.
3. An *increase* in both the force of the heart and the peripheral resistance; and it is further apparent that if the pressure is *higher* than the normal it may be lowered to the normal by a decrease in either one or both of these factors.

It is also apparent that the arterial blood-pressure as a whole may be decreased below the normal by:

1. *A decrease* in the rate and force of the heart's contraction.
2. A *decrease* in the peripheral resistance.
3. A *decrease* in both the force of the heart and the peripheral resistance; and it is again further apparent, that if the pressure is *lower* than the normal it may be raised to the normal by an increase in either one or both of these factors.

The Capillary Pressure.—The capillary pressure, though possessing an average value, may be increased by a relaxation of the arteriole muscle and decreased by their contraction. It may also be increased by any interference with the outflow from any given area, or decreased by factors which favor a larger outflow. Independently of any change in arteriole resistance, a rise of arterial pressure alone will increase the capillary pressure.

The Venous Pressure.—The venous pressure as a whole will be increased by a fall in arterial pressure as when the arterioles relax and the heart diminishes in force; it will be decreased if the opposite factors prevail.

The Pulse.—The pulse may be defined as a periodic expansion and recoil of the arterial system. The expansion is caused by the ejection into the arteries of a volume of blood during the systole; the recoil is due to the reaction of the arterial walls on the blood driving it forward into and through the capillaries, during the diastole.

At the close of the cardiac diastole the arteries are full of blood and considerably distended. During the occurrence of the succeeding systole, the incoming volume of blood is accommodated by a movement forward of a portion of the general blood volume into the capillaries and a further distention of the arteries. The distention naturally begins at the beginning of the aorta. As the blood continues to be discharged from the heart, adjoining segments of the aorta expand in quick succession and by the end of the systole the expansion has travelled over the arterial system as far as the capillaries. This expansion movement which passes over the arterial system in the form of a wave is known as the *pulse wave*, or the *pulse*. It is this alternate expansion and recoil which is perceived by the finger when placed over the course of an artery. The artery best adapted for this purpose is the radial as it passes across the wrist-joint.

The Radial Pulse.—If the ends of the fingers are firmly placed over the radial artery, not only the increase and decrease of pressure, but also many of the peculiarities of the pulse-wave, may be perceived. Without much difficulty it may be perceived that the expansion takes place quickly, the recoil relatively slowly; that the waves succeed one another with a certain frequency, corresponding to the heart-beat; that the pulsations are rhythmic in character, etc.

Inasmuch as the individuality of the pulse-wave varies at different periods of life and under different physiologic and pathologic conditions, various terms more or less expressive, have been suggested for its varying qualities. Thus the pulse is said to be *frequent* or *infrequent* according as it exceeds or falls short of a certain average number—72 per minute; *strong* or *weak* according to the energy with which the vessel expands; *quick* or *slow*, according to the suddenness with which the expansion takes place or strikes the fingers; *hard* or *soft*, *tense* or *easily compressible*, according to the resistance which the vessel offers to its compression by the fingers; *large*, *full* or *small*, according to the volume of blood ejected into the aorta, or, in other words, the degree of fullness of the arterial system.

The three qualities which are of most value to the clinician are rate, strength or force, and volume.

The Velocity of the Blood.—The velocity with which the blood flows in the arteries diminishes from the heart to the capillaries, owing to an enlargement in the united sectional area of the vessels; the velocity increases from the capillaries toward the heart for the opposite reason. The blood moves most rapidly in the large vessels, and especially under the influence of the ventricular systole. From experiments on animals, it has been estimated to move in the aorta of man at the rate of from 300 to 500 mm. a second, and in the large veins at the rate of from 150 to 250 mm. a second, and in the capillaries from 0.5 to 1 mm. per second.

The Pulmonic Vascular Apparatus.—The pulmonic vascular apparatus consists of a closed system of vessels extending from the right ventricle to the left auricle, and includes the pulmonic artery, capillaries, and pulmonic veins. In its anatomic structure and physiologic properties it closely resembles the systemic apparatus.

The flow of the blood through the arteries, capillaries and veins is characterized by velocity and pressure and in the pulmonic artery alone by the presence of the pulse. The causes of these phenomena in the pulmonic vascular apparatus are the same as in the systemic apparatus. The pressure in the pulmonic artery of the dog has been shown by Beutner to be about one-third that in the aorta; by Bradford and Dean to be one-fifth. Wiggers has recently shown that in normally breathing dogs with arterial pressures ranging from 110 to 112 mm. of mercury, the maximal or systolic pressure in the pulmonic artery averaged 36 mm., and the minimal or diastolic averaged 5 mm. The reason for the low pressure may be found in the large size and rich development of the pulmonic capillaries and the imperfect development of an arteriole muscle at the periphery of the pulmonic artery, the result of which is a diminution in the friction. Inasmuch as the friction is relatively low, the work of the right heart is less than that of the left heart and hence its walls are not so well developed. The pulmonic pressure being low the intraventricular pressure of the right heart is relatively low as compared with that of the left heart. The velocity of the blood-stream in each of the three divisions of the system cannot well be determined. The time occupied by a particle of blood in passing from the right to the left ventricle has been estimated at one-fourth the time required to pass from the left to the right ventricle. Assuming the latter to be thirty seconds, the former would be seven and one-half seconds.

The capillary vessels are spread out in a very elaborate manner just beneath the inner surface of the pulmonic air cells, and form, by their close relation to it, a mechanism for the excretion of carbon dioxid and the absorption of oxygen. The extent of the capillary surface is very great. It has been estimated at 200 square meters. The amount of blood flowing through this system hourly and exposed to the respiratory surface is about 430 liters. The reason for the existence of the pulmonary circulation is the renewal of the oxygen in the blood and the elimination of the carbon dioxid; for the accomplishment of both objects ample provision is here made. The flow of blood through the cardio-pulmonic vessels is subject to variation during both inspiration and expiration in consequence of their relation to the respiratory apparatus.

Forces Concerned in the Circulation of the Blood:

1. *The Contraction of the Heart.*—The primary forces which keep the blood flowing from the beginning of the aorta to the right side of the heart and from the beginning of the pulmonary artery to the left side are the contractions of the left and right ventricles respectively. Though the heart's energy is probably sufficient to drive the blood into the opposite side of the heart, it is supplemented by other forces—*e.g.*:

2. *Muscle Contraction.*
3. *Thoracic Aspiration.*
4. The *Action of the Valves* in the veins.

The Vaso-motor Nerves.—These are nerves that impart motor activity to the muscle-fibers of the arteriole walls, resulting either in an increase or decrease in the degree of their contraction and thus diminishing or increasing the outflow of blood. For this reason they are termed *vaso-augmentor* or *constrictor* nerves and *vaso-inhibitor* or *dilatator* nerves.

As the muscle-fibers belong to the autonomic tissues, the nerve supply to them consists of two consecutively arranged neurons, a pre-ganglionic and a post-ganglionic.

The pre-ganglionic vaso-constrictor neurons take their origin from nerve-cells located in the anterior horns and lateral gray matter of the spinal cord. They emerge from the cord in company with the fibers that compose the ventral roots of the spinal nerves from the second thoracic to the second or third lumbar nerves inclusive. A short distance from the cord they leave the ventral roots as the white rami communicantes and enter for the most part the vertebral or lateral sympathetic ganglia. From the results of many observations and experiments it is probable that the great majority of the vaso-constrictor nerves terminate in these ganglia; that is to say, it is here that the pre-ganglionic fibers arborize around the contained nerve-cells. From the nerve-cells the post-ganglionic fibers arise, which pass to the blood-vessels of (1) the body walls; (2) the fore-limbs; (3) the head, neck and face; (4) the hind limbs; and (5) the abdominal viscera.

The fibers for the blood-vessels of the abdominal viscera and which are contained in the trunk of the splanchnic nerve pass across the sympathetic chain and arborize around the nerve-cells in the semilunar ganglion. The post-ganglionic arise from the cells of this ganglion and then pass to the blood-vessels of the stomach, intestines, liver, etc.

The Vaso-motor Centers.—The vaso-motor centers for the spinal cord are dominated and controlled in their action by a group of nerve-cells in the floor of the fourth ventricle which is known as the general vaso-constrictor center. This center is supposed to consist of two groups of centers, viz., a vaso-tonic and a vaso-reflex center; the former maintains the vascular tonus while the latter permits of various vaso-motor reflexes.

The vaso-reflex center may be increased or decreased in its activity by nerve impulses transmitted to it from different regions of the body, in consequence of which the blood distributed to larger or smaller areas of the body is decreased or increased in accordance with their physologic needs.

Special vaso-dilatator centers are found in the medulla, for the blood-vessels of the glands of the mouth, nasal chambers, etc.; also in the lower lumbar region of the cord there are centers for the blood-vessels of the sexual organs. Stimulation of these centers, either reflexly, or directly from the cerebrum, causes dilatation of the vessels and a large inflow of blood.

RESPIRATION

Respiration is a process by which oxygen is introduced into, and carbon dioxid removed from the body. The assimilation of the former and the evolution of the latter take place in the tissues as a part of the general process of nutrition. Without a constant supply of oxygen and an equally constant removal of the carbon dioxid, those chemic changes which underlie and condition of life phenomena could not be maintained.

The general process of respiration may be considered under the following headings, viz.:

1. The anatomy and general arrangement of the respiratory apparatus.
2. The mechanic movements of the thorax by which an interchange of atmospheric and intra-pulmonary air is accomplished.
3. The chemistry of respiration; the changes in composition undergone by the air, blood, and tissues.
4. The nerve mechanism by which the respiratory movements are maintained and coördinated.

The Respiratory Apparatus.—The respiratory apparatus consists essentially of:

1. The lungs and the air-passages leading into them: viz., the nasal chambers, mouth, pharynx, larynx, and trachea.
2. The thorax and its associated structures.

The Larynx.—The larynx is composed of firm cartilages, united by ligaments and muscles. Running anteroposteriorly across the upper opening are four ligamentous bands—the two superior or *false* vocal bands, and the two inferior or *true* vocal bands—formed by folds of the mucous membrane. They are attached anteriorly to the thyroid cartilages and posteriorly to the arytenoid cartilages, and are capable of being separated by the contraction of the posterior crico-arytenoid muscles, so as to admit the passage of air into and from the lungs.

The Trachea.—The trachea is a tube from 10 to 12 centimeters in length, 2 centimeters in diameter, extending from the cricoid cartilage of the larynx to the fifth thoracic vertebra, where it divides into the right and left bronchi. It is composed of a series of cartilaginous rings, which extend about two-thirds around its circumference, the posterior third being occupied by transversely arranged non-striated muscle-fibers known as the *tracheal* muscle. Being attached to the ends of the cartilages it is capable, by alternately contracting and relaxing, of diminishing or increasing the lumen of the trachea. Opposite the fifth thoracic vertebra the trachea divides into a right and left bronchus. Each bronchus then subdivides into two other branches which penetrate the corresponding lung about the middle of the inner surface.

The Lungs.—The lungs, in the physiologic condition, occupy the greater part of the cavity of the thorax. They are separated from each other by the contents of the mediastinal space: viz., the heart, the large blood vessels, the esophagus, etc.

A histologic analysis of the lung shows it to consist of the branches of the bronchi, their subdivisions and ultimate terminations, blood-vessels, lymphatics and nerves, imbedded in a stroma of fibrous and elastic tissue. The anatomic relations which these structures bear one to another is as follows:

Within the substance of the lung the bronchi divide and subdivide, giving origin to a large number of smaller branches, *the bronchial tubes*, which penetrate the lung in all directions (Fig. 12). With this repeated subdivision the tubes become narrower, their walls thinner, their structure simpler. In passing from the larger to the smaller tubes the cartilaginous arches become shorter and thinner, and finally are represented by small angular and irregularly disposed plates. In the smallest tubes the cartilage entirely disappears. With the diminution of the caliber of the tube and a decrease in the thickness of its walls, there appears a layer of non-striated muscle-fibers, the so-called *bronchial muscle*, between the mucous and submucous tissues, which completely surrounds the tube and becomes especially well developed in those tubes devoid of cartilage. The fibrous and mucous coats at the same time diminish in thickness.

When the bronchial tube has been reduced to the diameter of about one millimeter, it is known as a *bronchiole* or a *terminal bronchus*. From the sides of the terminal bronchus and from its final termination there is given off a series of short branches which sooxpan end to form *lobules* or *aleveoli*. The cavity of the alveolus is termed the infundibulum. From the inner surface of the alveolus and of the passageway leading into it, there project thin partitions which subdivide the outer portion of the general cavity or infundibulum into small spaces, the so-called air-sacs or air-cells. The wall of the alveolus is extremely thin and consists of fibro-elastic tissue, supporting a very elaborate capillary network of blood-vessels. The bronchial system as far as the alveolar passages is lined by ciliated epithelium. The air-sacs are lined by flat epithelial plates of irregular shape, termed the *respiratory epithelium*. The alveoli are united one to another by fibro-elastic tissue.

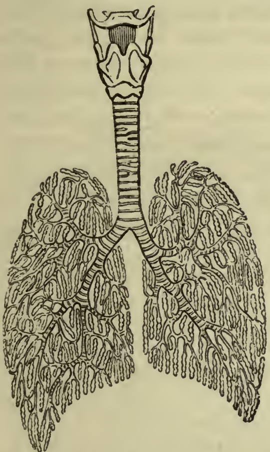

FIG. 12.—DIAGRAM OF THE RESPIRATORY ORGANS.

The windpipe, leading down from the larynx, is seen to branch into two large bronchi, which subdivide after they enter their respective lungs.

Bronchial Innervation.—The bronchial muscles are presumably in a state of tonic contraction and impart to the bronchial tubes a certain average caliber best adapted for respiratory purposes. Experimental investigations indicate that they are innervated by efferent fibers of the vagus nerve (broncho-constrictors and possibly broncho-dilatators) inasmuch as stimulation of this nerve is usually followed by a contraction of the muscles and a narrowing of the lumen of the bronchial system. These muscles may also be thrown into increased acitivity by the inhalation of irritating gases and into a tetanus by pathologic causes as seen in the various forms of asthma.

The Pulmonic Blood-vessels.—The two main divisions of the pulmonic artery distribute the venous blood to the pulmonic lobules. As the lobules are approached a small arterial branch plunges into the wall of the lobule, in which its branches form a rich capillary network in which surrounds and embraces the air sacs on all sides. The blood emerging from the capillaries is conducted by the converging system of veins—the pulmonic veins—into the left auricle of the heart. The main function of the pulmonic apparatus and the pulmonic division of the circulatory apparatus is to afford a ready means for the exhalation of the carbon dioxid and the absorption of oxygen. In consequence of this exchange of gases the blood changes in color from dark bluish-red to scarlet red.

The Thorax.—The thorax in which the respiratory organs are lodged, is of a conic shape, having its apex directed upward, its base downward. Its framework is formed posteriorly by the spinal column, anteriorly by the sternum, and laterally by the ribs and costal cartilages. Between and over the ribs lie muscles, fascia, and skin; above, the thorax is completely closed by the structures passing into it and by the cervical fascia and skin; below, it is closed by the diaphragm. It is, therefore, an air-tight cavity.

The Pleura.—Each lung is surrounded by a closed serous membrane (the pleura), one layer of which (the *visceral*) is reflected over the lung; the other (the *parietal*), reflected over the wall of the thorax; between the two layers is a small amount of fluid, which prevents friction during the play of the lungs in respiration.

The Relation of the Respiratory Organs.—*Intra-pulmonic pressure.*—When the thorax is in a condition of rest, as at the end of an expiration the lungs are full of air and by reason of their distensibility completely fill all portions of the thorax not occupied by the heart, great vessels, and esophagus. This condition is maintained by the pressure of the air in the lungs, the *intra-pulmonic pressure*, which is that of the atmoshpere 760 mm. Hg. This relation persists so long as the thorax remains air tight. If, however, an opening be made in the thoracic wall, the lung immediately collapses and a pleural cavity is established. The pressure of air within and without the lung counterbalancing, at the moment the air is admitted, the elastic tissue at once recoils and forces a large part of the air out of the lung. This is a proof that in the normal condition, the lungs, distended by atmospheric pressure from within, are in a state of elastic tension and ever endeavoring to pull the pulmonic layer of the pleura away from the parietal layer. That they do not succeed in doing so is due to the fact that the atmospheric pressure from without is prevented from acting on the lung by the firm unyielding walls of the thorax.

Intra-thoracic Pressure.—As a result of the elastic tension of the lungs a fractional part of the intra-pulmonic pressure, 760 mm. Hg., is counterbalanced or opposed, so that the heart and great vessels and other intrathoracic viscera are subjected to a pressure somewhat less than that of the atmosphere; the amount of this pressure will be that of the atmosphere *less* that exerted by the elastic tissue of the lung in the opposite direction, expressed in terms of millimeters of mercury. In the thorax, but outside the lungs, there then prevails a pressure, negative to the pressure inside the lungs and which is known as the *intra-thoracic pressure.*

The elastic tension of the lung has been determined for the human lung and amounts to about 6 mm. Hg. The intra-thoracic pressure is negative to the intra-pulmonic pressure by 6 mm. Hg.

The Respiratory Movements.—As the blood flows through the pulmonic capillaries it yields carbon dioxid to, and receives oxygen from, the air in the pulmonic alveoli. As a result, the intra-pulmonic air changes in composition, which interferes to a greater or less extent with the further exchange of gases. That this exchange may continue, it is of primary importance that the air within the alveoli be renewed as rapidly as it is vitiated. This is accomplished by an alternate increase and decrease in the capacity of the thorax, accompanied by corresponding changes in the capacity of the lungs. During the former there is an inflow of atmospheric air (inspiration), during the latter an outflow of intra-pulmonic air (expiration). The continuous recurrence of these two movements brings about that degree of pulmonic ventilation necessary to the normal exchange of gases between the blood and the air. The two movements together constitute a respiratory act or cycle.

1. *Inspiration* is an active process, the result of the expansion of the thorax, whereby the atmospheric air is introduced into the lungs.

2. *Expiration* is a partially passive process, the result of the recoil of the elastic walls of the thorax, and the recoil of the elastic tissue of the lungs whereby the intrapulmonary air is expelled.

In inspiration the chest is enlarged by an increase in all its diameters—viz.:

1. The *vertical* is increased by the contraction and descent of the diaphragm.

2. The *anteroposterior* and *transverse* diameters are increased by the elevation and rotation of the ribs upon their axes.

In *ordinary tranquil inspiration* the muscles which elevate the ribs and thrust the sternum forward, and so increase the diameters of the chest, are the *external intercostals*, running from above downward and forward; the *sternal portion* of the *internal intercostals*, and the *levatores costarum.*

In the *extraordinary efforts of inspiration* certain auxiliary muscles are brought into play—viz., the *sternomastoid*, *pectorales*, *serratus magnus*—which increase the capacity of the thorax to its upmost limit.

In expiration the diameters of the chest are all diminished—viz.:

1. The *vertical*, by the ascent of the diaphragm.

2. The *anteroposterior*, by a depression of the ribs and sternum.

In *ordinary tranquil expiration* the diameters of the thorax are diminished by the recoil of the elastic tissue of the lungs and the ribs; but in forcible expiration the muscles which depress the ribs and sternum, and thus further diminish the diameter of the chest, are the *internal intercostals*, the *infracostals*, and the *triangularis sterni*.

In the *extraordinary efforts of expiration* certain auxiliary muscles are brought into play—viz., the *abdominal* and *sacrolumbalis muscles*—which diminish the capacity of the thorax to its utmost limit.

The Movements of the Lungs.—By reason of the distensibility and the elastic recoil of the lungs, they follow all variations in the size of the thorax enlarging during inspiration to accommodate the incoming volume of air and diminishing during expiration to assist in the removal of a corresponding amount of air.

During the enlargement of the thorax, the intra-pulmonic air expands and its pressure falls in consequence of which the atmospheric air rushes in to restore atmospheric pressure. Coincidently the lungs are expanded and kept in close contact with the thoracic walls and the diaphragm. During the diminution in the size of the thorax, the intra-pulmonic air is compressed and its pressure rises, in consequence of which the intra-pulmonic air rushes out through the air passages until the atmospheric pressure is reached. Coincidently the elastic recoil of the lungs restores them to their former size and volume.

The *intra-thoracic pressure* falls during inspiration and rises during expiration. The expansion of the lungs is attended by an increase in the elastic recoil and hence a neutralization of a larger percentage of the *intra-pulmonic pressure*. The recoil of the lungs during expiration has the opposite result.

The fall of intra-thoracic pressure has a favorable influence on the flow of blood from the extra-thoracic veins into the intra-thoracic veins, the right side of the heart and the cardio-pulmonic vessels. The flow of lymph from the lower portion of the thoracic duct into the upper portion is also increased. During expiration the reverse movement is prevented by the action of the valves.

Types of Respiration.—Observations of the respiratory movements in the two sexes shows that while the enlargement of the thoracic cavity is accomplished both by the descent of the diaphragm (as shown by the protrusion of the abdomen) and the elevation of the thoracic walls, the former movement preponderates in the male, the latter in the female, giving rise to what has been termed in the one case the *diaphragmatic* or *abdominal* type and in the other the *thoracic* or *costal* type of respiration. Modern methods of investigations have established the view that the preponderance of thoracic movement is due to the influences of dress restrictions, for with their removal the so-called costal type of breathing entirely disappears. While gestation may lead to a greater activity of the thorax, this is but temporary, for with its termination there is a return to the diaphragmatic type of breathing.

Number of Respirations per Minute.—The number of respirations which occur in a unit of time varies with a variety of conditions, the most important of which is age. The results of the observations of Quetelet on this point, which are generally accepted, are as follows:

Age	Respirations per minute	Age	Respirations per minute
0– 1 year	44	20–25 years	18.7
5 years	26	25–30 years	15.0
15–20 years	20	30–50 years	17.0

From these observations it may be assumed that the average number of respirations in the adult is eighteen per minute, though varying from moment to moment from sixteen to twenty. During sleep, however, the respiratory movements often diminish in number as much as 30 per cent., at the same time diminishing in depth.

Volumes of Air Breathed.—The volumes of air which enter and leave the lungs with each inspiration and expiration naturally vary with extent of the movement, though four volumes at least, may be determined· (1) that of an ordinary inspiration; (2) that of an ordinary expiration; (3) that of a forced inspiration; (4) that of a forced expiration.

By means of the spirometer the amount of the foregoing four volumes have been determined and named as follows:

1. The *tidal* volume, that which flows into and out of the lungs with each inspiration and expiration, which varies from 20 to 30 cubic inches (330 to 500 c.c.).
2. The *complemental* volume, that which flows into the lungs, in addition to the tidal volume, as a result of a *forcible inspiration*, and which amounts to about 110 cubic inches (1,800 c.c.).
3. The *reserve* volume, that which flows out of the lungs, in addition to the tidal volume, as a result of a *forcible expiration*, and which amounts to about 100 cubic inches (1,650 c.c.).

After the expulsion of the reserve volume there yet remains in the lungs an unknown volume of air which serves the mechanic function of distending the air-cells and alveolar passages, thus maintaining the conditions essential to the free movement of blood through the capillaries and to the exchanges of gases between the blood and alveolar air. As this volume of air cannot be displaced by volitional effort, but resides permanently in the alveoli and bronchial tubes though constantly undergoing renewal, it was termed—

4. The *residual* volume, the amount of which is difficult of determination, but has been estimated by different observers at 914 c.c. 1,562 c.c., 1,980 c.c.

The Vital Capacity of the Lungs.—The total volume of the air in the lungs at the time of their maximum distention represents the vital capacity in the physiological condition and includes the tidal, the complemental, the reserve and the residual air. The vital capacity, however, has been defined as the amount of air which can be expelled by the most forcible expiration after the most forcible inspiration, this therefore *excludes* the residual volume. The vital capacity was supposed to be an indication of an individual's respiratory power, not only in physiologic but also in pathologic conditions. Though averaging about 230 cubic inches (3,770 c.c.) for an individual 5 feet 7 inches in height, the vital capacity varies with a number of conditions, the most important of which is stature. It is found that between 5 and 6 feet the capacity increases 8 inches (130 c.c.) for each inch increase in height.

The *total volume* of air breathed daily can be approximately determined by multiplying the average volume of air taken in at one inspiration and multiplying by the number of respirations per minute. Assuming that an individual takes into the lungs at each inspiration 330 to 500 c.c. (20 to 30 cubic inches) and at the same time breathes 18 times per minute there would pass into the lungs during the twenty-fours, 8,500 to 12,752 liters.

The Chemistry of Respiration. Changes in the Composition of the Air Breathed.—Experience teaches that the air during its sojourn in the lungs undergoes such a change in composition that it is rendered unfit for further breathing. Chemic analysis has shown that this change involves a loss of oxygen, a gain in carbon dioxid, watery vapor, and organic matter. For the correct understanding of the phenomena of respiration it is essential that not only the character but the extent of these changes be known. This necessitates an analysis of both the inspired and expired airs, from a comparison of which certain deductions can be made.

The results which have been obtained are represented in the following table:

	Inspired air			Expired air	
100 vols.	Oxygen	20.80.	100 vols.	Oxygen	16.02.
	Carbon dioxid	traces.		Carbon dioxid	4.38.
	Nitrogen	79.20.		Nitrogen	79.60.
	Watery vapor	variable.		Watery vapor	saturated.
				Organic matter	a trace.

These analyses indicate that under ordinary conditions the air loses oxygen to the extent of 4.78 per cent. and gains carbon dioxid to the extent of 4.38 per cent.; that it gains in nitrogen to the extent of 0.4 per cent. and in watery vapor from its initial amount to the point of saturation, as well as in organic matter. It is to these changes in their totality that those disturbances of physiologic activity are to be attributed which arise when expired air is re-breathed for any length of time without having undergone renovation. From the percentage loss of oxygen and gain in carbon dioxid the *total oxygen absorbed* and *carbon dioxid exhaled* may be approximately calculated. Thus, if the volume of air breathed daily be accepted at either 8,500 or 12,752 liters, and the percentage loss of oxygen be 4.78, the total oxygen absorbed may be obtained by the rule of simple proportion, *e.g.:*

$$100 : 4.78 :: 8{,}500 : x = 406 \text{ liters or } 580 \text{ grams}$$[1]

Or

$$100 : 4.78 :: 12{,}752 : x = 609 \text{ liters or } 870 \text{ grams.}$$

By the same method the total carbon dioxid exhaled is found to be either 372 liters or 735 grams, or 558 liters or 1,103 grams, volumes in both instances which agree very well with volumes obtained by other methods.

As there is always more oxygen consumed than carbonic acid exhaled, and as oxygen unites with carbon to form an equal volume of carbonic acid, it is evident that a certain quantity of oxygen disappears within the body. In all probability it unites with the surplus hydrogen of the food to form water.

The quantities both of oxygen absorbed and carbon-dioxid exhaled daily is subject to considerable variation. They are increased by exercise, digestion and a lowered temperature, and decreased by the opposite conditions.

The gain in watery vapor will depend on the amount previously present in the air. This is conditioned by the temperature. With a rise in temperature the percentage of water increases; with a fall, it decreases.

[1] 1 liter of oxygen weighs 1.4298 grams; 1 liter of carbon dioxid weighs 1.977 grams.

The gain in organic matter is also variable. The amount present is not sufficient to permit of a thorough chemic analysis, but there are reasons for believing that it belongs to the protein group of bodies. If it accumulates in the air, especially at high temperatures, it readily undergoes decomposition, with the production of offensive odors. Traces of free ammonia have also been found in the expired air. In addition to these chemic changes, the air experiences physical changes; *e.g.*, a rise in temperature and an increase in volume. The rise in temperature can be shown by breathing through a suitable mouthpiece into a glass tube containing a thermometer. By this means it has been shown that inspired air at 20°C. rises in temperature to 37°C.; at 6.3° to 29.8°C. The increase in the temperature will depend upon that of the air inspired and the time it remains in the lungs. If retained a sufficient length of time it will always become that of the body.

Changes in the Composition of the Blood.—As the blood of the pulmonic artery passes through the pulmonic capillaries, it loses carbon dioxid and gains oxygen, in consequence of which, it changes in color from a bluish red to a scarlet red. As the blood of the systemic arteries flows into and through the systemic capillaries it loses oxygen and gains carbon dioxid in consequence of which it changes in color from a scarlet red to a bluish red.

The Gases of the Blood.—The presence of gases in the blood is demonstrated by subjecting it to the vacuum of the air pump into which they at once escape.

An analysis of the gases so obtained gives the following results.

Arterial blood 100 vols.	Oxygen.......	20 vols.	Venous blood 100 vols.	Oxygen.......	12 vols.
	Carbon dioxid.	40 vols.		Carbon dioxid.	45 vols.
	Nitrogen......	1–2 vols.		Nitrogen......	1–2 vols.

The changes produced in the blood by respiration, both external and internal, become apparent from a comparison of these analyses. The arterial blood while passing through the capillaries of the tissues loses eight volumes per cent. of oxygen and gains five per cent. of carbon dioxid. The venous blood while passing through the capillaries of the lungs gains oxygen and loses carbon dioxid in corresponding amounts. These amounts will vary somewhat in the analyses of the blood of different animals and under different physiologic conditions. The volume of nitrogen is not appreciably changed.

The Condition of the Gases in the Blood.—After the oxygen of the alveoli passes across the thin alveolo-capillary wall into the blood it combines with hemoglobin to form oxy-hemoglobin, the compound that gives the scarlet-red color to the arterial blood. As the arterial blood flows into the capillary vessels the oxygen is in part dissociated from the hemoglobin and passes across the capillary wall into the tissues.

The carbon dioxid arising in the tissues passes across the capillary wall into the blood where a portion of it is physically absorbed, while another portion combines with sodium carbonate to form a bicarbonate. As the blood passes through the pulmonic capillaries the carbon dioxid is in part dissociated and then passes across the alveolo-capillary wall into the interior of the alveoli.

Changes in the Composition of the Tissue Fluids.—An analysis of the tissue fluids shows the absence of oxygen and the presence of carbon dioxid. Notwithstanding the continuous passage of oxygen across the capillary walls into the tissue fluids free oxygen cannot be determined in them. The absence of oxygen would indicate that it is immediately utilized by the tissue with the production of carbon dioxid; or that it is stored in the tissues in some form or other by which it can be retained until required for oxidation purposes—the latter is the more likely view.

The carbon dioxid is present in variable quantities in the tissues and fluids and though passing into the blood at varying rates it is as constantly being evolved.

The Mechanism of the Gaseous Exchange.—The passage of the oxygen from the alveoli into the blood and into the tissues, and the passage of the carbon dioxid from the tissues into the blood and into the alveoli is believed to be due to differences of pressure. In the alveoli the oxygen pressure is approximately equal to 130 mm. of Hg.; in the arteries 106 mm. Hg. and in the tissues zero. In the tissues the carbon-dioxid pressure varies from 45 to 68 mm. of Hg.; in the veins 42 mm. Hg. and in the alveoli about 38 mm. Hg. In these differences of pressure is to be found an explanation for the exchange of these gases.

The Total Respiratory Exchange.—The total quantities of oxygen absorbed and carbon dioxid discharged by a human being in twenty-four hours are measures of the intensity of the respiratory process, and an indication of the extent and character of the chemic changes attending all life phenomena.

Approximate amounts of oxygen absorbed and carbon dioxid exhaled as determined by different investigators are as follows:

Oxygen absorbed	Observer	Carbon dioxid discharged
746 grams.	Vierordt.	876 grams.
700 grams.	Pettenkofer and Voit.	800 grams.
663 grams.	Speck.	770 grams.

The amounts of oxygen absorbed in Pettenkofer and Voit's experiments varied from 594 to 1,072 grams; of carbon dioxid exhaled, from 686 to 1,285 grams.

The Nerve Mechanism of Respiration.—The simultaneous and coördinated activity of the inspiratory muscles implies the simultaneous and coördinated activity of nerve centers and their related motor nerves. Thus the action of the nasal and laryngeal muscles (the dilatator naris and the posterior crico-arytenoid) involves the activity of the facial and inferior laryngeal nerves respectively, the centers of origin of which lie in the gray matter beneath the floor of the fourth ventricle; the diaphragm and intercostal muscles involve respectively the activity of the phrenic and intercostal nerves, the centers of origin of which lie in the anterior horn of the gray matter of the spinal cord at a level, for the phrenic, of the fourth, fifth, and sixth cervical nerves, and for the intercostals at the level of the thoracic nerves. Division of any one of these nerves is followed by paralysis of its related muscle.

Inspiratory Center.—The coördinate contraction of the inspiratory muscles implies a practically simultaneous discharge of nerve impulses from each of the foregoing nerve-centers, accurately graduated in intensity in accordance with inspiratory needs. This has been supposed to necessitate the existence in the central nerve system of a single group of nerve-cells from which nerve impulses are rhythmically discharged and conducted to the previously mentioned nerve-centers in the medulla oblongata and spinal cord, by which they are in turn excited to activity. To this group of cells the term "inspiratory center" has been given.

The rhythmic activity of the inspiratory center is in part the result of the stimulating action of carbon dioxid and partly the result of the transmission to it of nerve impulses from various regions of the body. The irritability of the center is markedly increased by the percentage of carbon dioxid in the blood and decreased by the opposite condition. The vagus nerves of all afferent nerves are the most influential in maintaining the normal rhythmic discharge of nerve impulses from the inspiratory center as shown by the effects that follow their separation from the center. Thus, if while the animal is breathing regularly and quietly both vagi are cut, the respiratory movements become much slower, falling perhaps to one-third their original number per minute. At the same time the inspirations become deeper and somewhat spasmodic in character. The duration of the inspiratory movement is also increased beyond that of the expiratory movement. If now the central end of one of the divided vagi be stimulated with weak induced electric currents, the respiratory movements are again increased in frequency, and their depth diminished until the normal rate is restored. With the cessation of the stimulation the former condition at once returns. This would seem to indicate that the vagus nerve contains nerve-fibers which, under physiologic conditions, transmit nerve impulses which *inhibit* the inspiratory discharge and lead to an expiratory movement sooner than would otherwise be the case, and thus maintain the normal rate and extent of the inspiratory charge.

Stimulation of the central end of the divided vagus with strong electric currents excites the activity of the inspiratory center to such an extent, that the muscles pass into the tetanic state and the thorax comes to rest in the condition of a forced inspiration.

These results indicate that the vagus nerve contains two classes of fibers which influence the activity of the inspiratory center, viz.: an *excitator* and an *inhibitor*. The stimulus to their excitation is to be found in the alternate recoil and expansion of the alveoli, in the walls of which they terminate. With the recoil of the alveolar walls nerve impulses are developed which ascend the vagi to the inspiratory center and excite it to activity and thus call forth a new inspiratory movement sooner than it would otherwise take place. With the expansion of the alveoli, nerve impulses are developed which ascend the vagi to the inspiratory center and inhibit its activity and thus lead to an expiratory movement sooner than it would otherwise take place. The respiratory mechanism is apparently self-regulative and maintained by the alternate recoil and expansion of the lungs.

The Establishment of Respiration after Birth.—During intra-uterine life the exchange of gases is accomplished by the placenta. Immediately after birth, this method is abolished. The cause of the first inspiration therefore must be associated with an increase in the percentage of carbon dioxid or a decrease in the percentage of oxygen in the blood. The former condition is more likely to be the efficient cause. The rapid accumulation of carbon dioxid with its increasing pressure in the inspiratory center so raises its irritability, as to lead to a discharge of nerve impulses which are conducted to the inspiratory muscles and cause their contraction. With the first inspiration thus established the nerve mechanism comes into play.

Inasmuch as cold water applied to the skin of the adult profoundly excites at times the inspiratory center it has been assumed that an additional factor leading to an excitation of the inspiratory center is the rapid cooling of the surface of the child by the evaporation of the amniotic fluid from the surface of the skin. The nerve impulses thus developed are transmitted through cutaneous nerves to the inspiratory center. This assumption is somewhat strengthened by the fact that in delayed inspiration the stimulation of the skin by the application of cold water frequently leads to a sudden inspiratory movement.

ANIMAL HEAT

The animal body possesses a temperature that is perceptible to the sense of touch and determinable by a thermometer. This temperature is the result of the liberation of heat which attends the chemic changes taking place in the tissues and organs of the living body and which underlie all manifestations of life. In consequence of this each animal acquires a certain body-temperature.

The *normal temperature* of the body in the adult, as shown by means of a delicate thermometer placed in the axila, ranges from 97.25°F. to 99.5°F., though the *mean normal* temperature is estimated by Wunderlich at 98.6°F.

The temperature varies in different portions of the body however, according to the extent to which oxidation rakes place, being highest in the muscles, in the brain, blood, liver, etc.

Variations in the Mean Temperature.—The **conditions which produce variations** in the normal temperature of the body are: age, period of the day, exercise, food and drink, climate, season, and disease.

Age.—At birth the temperature of the infant is about 1°F. above that of the adult, but in a few hours falls to 95.5°F., to be followed in the course of twenty-four hours by a rise to the normal or a degree beyond. During childhood the temperature approaches that of the adult; in aged persons the temperature remains about the same, though they are not so capable of resisting the depressing effects of external cold as adults. A *diurnal variation* of the temperature occurs from 1.8°F. to 3.7°F. (Jürgensen); the *maximum* occurring late in the afternoon, from 4 to 9 P. M.; the *minimum*, early in the morning, from 1 to 7 A. M.

Exercise.—The temperature is raised from 1° to 2°F. during active contractions of the muscular masses, and is probably due to the increased activity of chemic changes; arise beyond this point being prevented by its diffusion to the surface, consequent on a more rapid circulation, radiation, more rapid breathing, etc.

Food and Drink.—The ingestion of a hearty meal increases the temperature but slightly; an absence of food, as in starvation, produces a marked decrease. Alcoholic drinks, in large amounts, in persons unaccustomed to their use, cause a depression of the temperature amounting to from 1° to 2°F. Tea causes a slight elevation.

External Temperature.—Long-continued exposure to cold, especially if the body is at rest, diminishes the temperature from 1° to 2°F., while exposure to a great heat slightly increases it.

Disease frequently causes a marked variation in the normal temperature of the body, which rises as high as 107°F. in typhoid fever and 105°F. in pneumonia; in cholera it falls as low as 80°F. Death usually occurs when the heat remains high and persistent, from 106° to 110°F.; the increase of heat in disease is due to excessive production rather than to diminished elimination.

The Residual Heat of the Body.—As a preliminary to a consideration of heat-production and heat-dissipation, it is of interest to determine the actual quantity of heat expressed in Calories, that resides in the body at all times. This can be approximately determined from the chemic composition and the temperature. A chemic analysis of the body shows that it consists of water 0.6, and of tissue 0.4. If the weight be assumed to be 70 kilograms then 42 kilograms consist of water, and as the temperature is 37°C., the 42 kilos of water will contain 42 × 37 or 1,554 kilogram calories; the remaining 28 kilograms consist of tissues, the specific heat of which is but 0.8 that of water, hence the 28 kilograms of tissue will contain 28 × 0.8 calories; the equivalent of 22.4 kilograms of water. Since the temperature of the body is 37°C. the additional number of Calories will be 22.4 × 37 or 828, making a total of 2,382 Calories an amount of heat absolutely necessary to maintain the body-temperature at the physiological level. Notwithstanding the constant liberation of large amounts of heat each day, it is dissipated more or less rapidly in accordance with variations in temperature, character of clothing and a variety of other conditions, and so accurately is this done, that at the end of the twenty-four hours the body possesses its customary quantity of heat and its physiologic temperature.

Heat Production. Thermogenesis.—The immediate source of the body heat is to be found in the chemic changes that take place in all the tissues and organs of the body.

Every contraction of a muscle, every act of secretion, each exhibition of nerve force, is accompanied by a change in the chemic composition of the tissues and an evolution of heat. The reduction of the disintegrated tissues to their simplest form by oxidation, and the combination of the oxygen of the inspired air with the carbon and hydrogen of the blood and tissues, results in the formation of carbonic acid and water and the liberation of a great amount of heat.

Certain elements of the food, particularly the *carbo-hydrates* and the *fats*, undergo oxidation without taking part in the formation of the tissues, being transformed into carbon dioxid and water, and thus increase the sum of heat in the body.

The total quantity of heat liberated each day may be approximately determined in at least two ways: (1) by determining experimentally the heat values of different food principles by direct oxidation; (2) by collecting and measuring with a suitable apparatus, a calorimeter, the heat evolved by the oxidation of the food within, and dissipated from, the body daily.

By the direct oxidation of the food principles by means of a calorimeter, it has been determined, when they are burned to carbon dioxid and water, that 1 gram of protein yields approximately 5.6 Calories, 1 gram of fat 9.353 C. and 1 gram of starch or sugar 4.116 C. In the body fat and sugar or starch are also burned to carbon dioxid and water. The protein, however, is only in part burned to this extent; a part is changed to urea which when eliminated carries with it a portion of the original heat of the protein. In the body the protein yields 4.124 Calories. The total number of calories liberated by the various diet scales (see page 53) can be readily determined by multiplying the quantities of the food principles by the foregoing factors. The diet scale of Vieordt, for example, yields the following:

120 grams of protein	494.88 Calories
90 grams of fat	841.77 Calories
330 grams of starch	1,358.28 Calories
Total	2,694.93 Calories

The total calories obtained from other diet scales would be as follows: Ranke's, 2,335; Voit's, 3,387; Moleschott's, 2,984; Atwater's, 3,331. These numbers indicate theoretically the total heat-production in the body daily.

The collection of the heat dissipated by a human being weighing 70 kilos when placed in a suitable calorimeter reveals the fact that it amounts to from 2,300 to 3,000 Calories.

The amount of heat liberated will naturally vary in accordance with a number of conditions but principally with variations as physiologic activity, the quantity and quality of food and changes in the external temperature. The chief factor that increases metabolism and hence heat production is a low external temperature. This in turn leads to increased physical activity and increased food consumption. The heat-production and elimination under such circumstances may reach 4,700 Calories a day.

Heat Dissipation. Thermolysis.—From the preceding statements it is evident that the body is continually liberating heat in amounts daily far in excess of that necessary for the maintenance of the body-temperature. Should this heat be retained, the temperature of the body would be raised at the end of twenty-four hours an additional 18° or 20°C.—a temperature far in excess of that compatible with the maintenance of physiologic processes. That the body may be kept at the mean temperature of 37°C. it is essential that the heat liberated be dissipated as fast as it is produced, or to state the problem in another way, the heat dissipated by the body must be replaced by an equal amount liberated, if equilibrium of temperature is to be maintained. The dissipation of the heat is accomplished in several ways:

Assuming 2,500 Calories to be an average of heat liberated during a day of repose, the losses, in the ways stated in the foregoing paragraph, may be tabulated as follows:

1. *In Warming Food and Drink.*—The average temperature of food and drink is about 12°C.; the amount of both together is about 3 kilograms; the specific heat of food about 0.8 that of water. The absorption of body-heat, therefore, by the food amounts approximately to $3 \times 0.8 \times 25°C. =$ 60 Calories = 2.8 per cent. With the removal of the end-products of the foods and drink from the body an equal amount of heat is carried out.

2. *In Warming the Inspired Air.*—The average temperature of the air is 12°C.; the amount of inspired air, about 15 kilograms; the specific heat of air, 0.26. The absorption of body-heat by the air until it attains the temperature of the body will, therefore, amount to $15 \times 0.26 \times 25° =$ 97.5 Calories = 3.8 per cent. The expired air removes from the body a corresponding amount.

3. *In the Evaporation of Water from the Lungs.*—The quantity of water evaporated from the lungs may be estimated at 400 grams; as each gram requires for its evaporation 0.582 Calorie, the quantity of heat lost by this channel would be $400 \times 0.582 = 232.8$ Calories = 9.4 per cent.

4. *In the Evaporation of Water from the Skin.*—The quantity of water evaporated from the skin may be estimated at 660 grams, causing a loss of heat by this channel of $660 \times 0.582 = 384.1$ Calories = 15.3 per cent.

5. *In Radiation and Conduction from the Skin.*—The amount of heat lost by this process can be indirectly determined only by subtracting the total amount lost by the above-mentioned channels from the total amount produced. Thus, $2{,}500 - 7{,}774.4 = 1{,}725.6$ Calories = 69 per cent. would represent the average amount lost by radiation and conduction.

Head dissipation is accomplished as shown in the foregoing tabulation mainly by radiation and conduction, 70 per cent., and by the evaporation of water from the lungs and skin, 25 per cent. The mechanism by which this dissipation is accomplished consists of the cutaneous and pulmonic blood-vessels and the sweat-glands which may be, therefore, regarded as thermolytic organs. The ratio of the heat loss between the evaporation of water and radiation will vary with the temperature, the season of the year, the character of the clothing, etc.

Inasmuch as the mean temperature of the body remains practically constant, notwithstanding seasonal variations, it is apparent that heat-dissipation must be exactly balanced by heat-production. Should there be any want of correspondence between the two processes, there would arise either an increase or a decrease in the mean temperature. As both heat-production and heat-dissipation are variable factors, dependent on a variety of internal and external conditions, their adjustment is accomplished by a complex self-regulating mechanism involving muscle, vascular, and secretor elements, coördinated by the nerve system.

EXCRETION

Excretion may be defined as the process by which the end-products of metabolism are removed from the body. As the retention of these end-products in the body would exert a deleterious influence on normal metabolism, their prompt removal becomes essential to the maintenance of physiologic activity. The principal excretions of the body—urine, perspiration, and bile—are, with the exception of those given off in the lungs, complex fluids in which are to be found in varying proportions the chief end-products of metabolism.

The chief excretory organs, therefore, are the kidneys, skin and lungs.

URINE

Normal urine is of a pale yellow or amber color, perfectly transparent, with an aromatic odor, an acid reaction, a specific gravity of 1,020, and a temperature when first discharged of 100°F.

The *color* varies considerably in health, from a pale yellow to a brown hue, owing to the presence of the coloring-matter, *urobilin* or *urochrome.*

The *transparency* is diminished by the presence of mucus, the calcium and magnesium phosphates, and the mixed urates.

The *reaction* of the urine is acid, owing to the presence of acid phosphate of sodium. The degree of acidity, however, varies at different periods of the day. Urine passed in the morning is strongly acid, while that passed during and after digestion, especially if the food is largely vegetable in character, is either neutral or alkaline.

The *specific gravity* varies from 1,015, to 1,025.

The *quantity* of urine excreted in twenty-four hours is between forty and fifty fluidounces, but ranges above and below this standard.

The *odor* is characteristic, and caused by the presence of taurylic and phenylic acids, but is influenced by vegetable foods and other substances eliminated by the kidneys.

The *chemic composition* of the urine is very complex and is determined partly by the metabolism of the constituents of the tissues and partly by the quantity and the quality of the food consumed and metabolized. Hence the composition will vary from day to day in accordance with the character of the food. An average composition is presented in the following table:

The Chemical Composition of Urine

Water	1500.00 c.c.
Total solids	72.00 grams.
Urea	33.18 grams.
Uric acid (urates)	0.55 grams.
Hippuric acid (hippurates)	0.40 grams.
Kreatinin, xanthin, hypoxanthin, guanin, ammonium salts, pigment, etc.	11.21 grams.
Inorganic salts; sodium and potassium sulphates, phosphates, and chlorids; magnesium and calcium phosphates. Organic salts: lactates, acetates, formates in small amounts	27.00 grams.
Sugar	a trace.
Gases, nitrogen, and carbonic acid.	

The Total Solids.—It is frequently a matter of clinic interest to determine the total amount of the solid constituents excreted in twenty-four hours. This may be attained approximately by multiplying the last two figures of the specific gravity by the coefficient, 2.33, of Haeser or Christison. The coefficient of Jones, 2.6, is believed by some observers to give more accurate results for conditions existing in this country. The result expresses the total solids in 1,000 parts: *e.g.*, urine with a specific gravity of 1.020 would contain 20 × 2.33, or 46.60 grams of solid matter per 1,000 c.c. If the amount passed in twenty-four hours be 1,500 c.c., the total solids would amount to 69.9 grams daily.

Organic Constituents of Urine.—Urea is one of the most important of the organic constituents of the urine, and is present to the extent of from 2.5

to 3.2 per cent. Urea is a colorless, neutral substance, crystallizing in four-sided prisms terminated by oblique surfaces. When crystallization is caused to take place rapidly, the crystals take the form of long, silky needles. Urea is soluble in water and alcohol; when subjected to prolonged boiling, it is decomposed, giving rise to carbonate of ammonia. In the alkaline fermentation of urine, urea takes up two molecules of water with the production of carbonate of ammonia.

The *average amount* of urea excreted daily has been estimated at about 34 grams. As urea is one of the principal products of the breaking up of the protein compounds within the body, it is quite evident that the quantity produced and eliminated in twenty-four hours will be *increased* by any increase in the amount of protein food consumed, or by a rapid destruction of protein tissues, as is observed in various pathologic states, inanition, febrile conditions, fevers, etc. A farinaceous or vegetable diet will diminish the urea production nearly one-half.

Muscular exercise when the nutrition of the body is in a state of equilibrium does not seem to increase the quantity of urea.

Seat of Formation and Antecedents of Urea.—As to the seat of urea formation there is some discussion. It is quite certain that urea pre-exists in the blood and is merely excreted by the kidneys. Experimental and pathologic facts point to the liver as the probable organ engaged in urea formation. Acute yellow atrophy of the liver, suppurative diseases of the liver, diminish almost entirely the production of urea, but increase the amount of the ammonium salts in the urine. The perfusion of the liver of a recently killed animal with a given amount of blood containing ammonium salts will be followed after the lapse of several hours by an amount of urea in the blood two or three times the normal quantity. These and other facts indicate that the chief seat of urea formation is to be found in the liver cells.

The antecedents of urea, out of which the hepatic cells construct urea have, for chemic reasons as well as from the foregoing experimental results, been shown to be the salts of ammonia, the carbonate, carbamate, and lactate. The source of the ammonia is probably in part the intestine, as this compound is one of the products of the hydrolysis and cleavage of the proteins during digestion. That this is the case is apparent from the fact that the blood of the portal vein always contains more ammonia than the blood of any other region of the vascular apparatus.

It has also been established that of the amino-acids circulating in the blood and tissues a certain number not needed for growth and tissue repair, undergo a cleavage into an NH_2 portion and a carbonaceous radicle. The former is then converted into ammonia and subsequently into urea by the liver cells or perhaps the muscles and other tissues as well. The protein constituents of the tissues may in their katabolism likewise yield the NH_2 element, which is also subsequently transformed into ammonia and urea.

Uric acid is also a constant ingredient of the urine and is closely allied to urea. It is a nitrogen-holding compound, carrying out of the body a portion of the nitrogen. The amount eliminated daily varies from 0.5 to 1 gram. Uric acid is a colorless crystal belonging to the rhombic system. It is insoluble in water, and if eliminated in excessive amounts, it is deposited as a "brick-red" sediment in the urine. It is doubtful if uric acid exists in a free state, being combined for the most part with sodium and potassium bases forming urates. It is to be regarded as one of the terminal products of the decomposition of nucleic acid which in turn is derived from nuclein, a constituent of cell nuclei.

Hippuric acid is found very generally in urine, though it is present only in small amounts. It is increased by a diet as asparagus, cranberries, plums, and by the administration of benzoic and cinnamic acids. It is probably formed in the kidney.

Kreatinin.—This is a crystalline nitrogenous compound closely resembling kreatin, one of the constituents of muscle-tissue. The amount excreted daily is about 1 gram. The origin of kreatinin is not very clear. It is probably, however, that if kreatin is capable of transformation into kreatinin a certain portion is derived from the kreatin contained in the meat consumed as food. But as kreatinin is steadily excreted though in less amounts on a diet from which meat is excluded it is certain that this portion at least must have some other source containing nitrogen, and the inference is that it is one of the end-products of the protein metabolism that is taking places in tissues generally and more particularly in muscle-tissue.

Xanthin, Hypoxanthin, Adenin, Guanin.—These compounds are also found in urine in small but variable amounts. They are nitrogenized compounds derived mainly from the metabolism of the nuclein bodies, and frequently spoken of as the purin bases.

Indol, Skatol, Phenol, Cresol.—These compounds, products of the putrefactive changes in the derivatives of protein are present in variable amounts, associated with potassium sulphate (see page 160). These compounds are known as the ethereal sulphates. The extent to which they are present is taken as a measure of the extent of intestinal putrefaction.

Inorganic Salts.—Sodium and potassium phosphates, known as the *alkaline phosphates*, are found in both blood and urine. The total quantity excreted daily is about 4 grams. Calcium and magnesium phosphates, known as the *early phosphates*, are present to the extent of 1 gram. Though insoluble in water, they are held in solution in the urine by its acid constituents. If the urine be rendered alkaline, they are at once precipitated. Sodium and potassium sulphate are also present to the extent of about 2 grams. The phosphoric and sulphuric acids which are combined with these bases enter the body for the most part in the foods, though there is evidence that they also arise by oxidation in consequence of the metabolism of proteins which contain phosphorus and sulphur. Sodium chlorid is the most abundant of the inorganic salts. It is derived mainly from the food. The amount excreted is about 15 grams in twenty-four hours.

KIDNEYS

The **kidneys** are the organs for the secretion of urine. They are situated in the lumbar region, one on each side of the vertebral column behind the peritoneum, and extend from the eleventh rib to the crest of the ilium; the anterior surface is convex, the posterior surface concave, the latter presenting a deep notch, the *hilus*.

The kidney is surrounded by thin, smooth membrane composed of white fibrous and yellow elastic tissue; though it is attached to the surface of the kidney by minute processes of connective tissue, it can be readily torn away. The substance of the kidney is dense, but friable.

Upon making a longitudinal section of the kidney it will be observed that the *hilus* extends into the interior of the organ and expands to form a cavity known as the *sinus*. This cavity is occupied by the upper, dilated portion of the ureter, the interior of which forms the *pelvis*. The ureter subdivides into several portions, which ultimately give origin to a number of smaller tubes, termed *calcyes*, which receive the apices of the pyramids (Fig. 13).

The **parenchyma of the kidney** consists of two portions—viz.:

1. *An internal* or *medullary portion*, consisting of a series of *pyramids* or *cones*, some twelve or fifteen in number. They present a distinctly striated appearance, a condition due to the straight direction of the tubules and blood vessels.

2. *An external* or *cortical portion*, consisting of a delicate matrix containing an immense number of tubules having a markedly convoluted appearance. Throughout its structure are found numerous small ovoid bodies, termed *Malpighian corpuscles*.

The Uriniferous Tubules.—The kidney is a compound, tubular gland composed of microscopic tubules whose function it is to secrete from the blood those waste products which collectively constitute the urine. If the

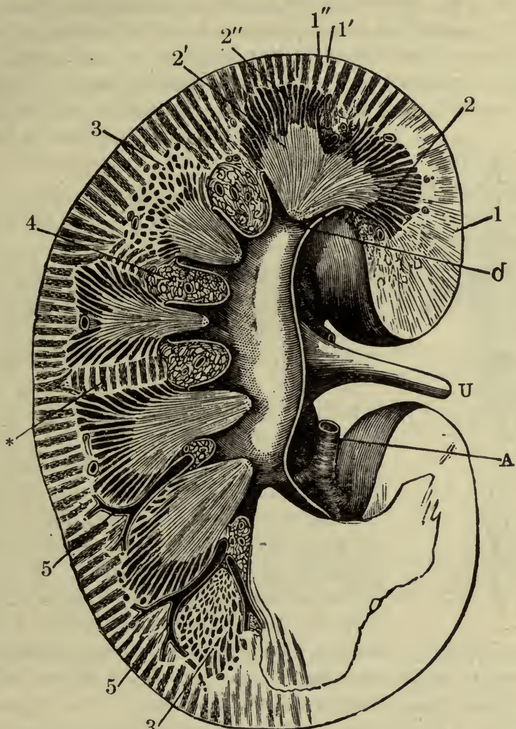

FIG. 13.—LONGITUDINAL SECTION THROUGH THE KIDNEY, THE PELVIS OF THE KIDNEY, AND A NUMBER OF RENAL CALYCES.—(*Tyson, after Henle.*)

A. Branch of the renal artery. *U*. Ureter. *C*. Renal calyx. 1. Cortex. 1′. Medullary rays. 1″. Labyrinth, or cortex proper. 2. Medulla. 2′. Papillary portion of medulla, or medulla proper. 2″. Border layer of the medulla. 3, 3. Transverse section through the axes of the tubules of the border layer. 4. Fat of the renal sinus. 5, 5. Arterial branches. * Transversely coursing medulla rays.

apex of each pyramid be examined with a lens, it will present a number of small orifices, which are the beginning of the uriniferous tubules. From this point the tubules pass outward in a straight but somewhat divergent manner toward the cortex, giving off at acute angles a number of branches

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(Fig. 14). From the apex to the base of the pyramids they are known as the tubules of Bellini. In the cortical portion of the kidney each tubule becomes enlarged and twisted, and after pursuing an extremely convoluted course, turns backward into the medullary portion for some distance, forming the descending limb of Henle's loop: it then turns upon itself, forming the ascending limb of the loop, reënters the cortex, again expands, and finally terminates in a spheric enlargement known as *Müller's* or *Bowman's capsule.* Within this capsule is contained a small tuft of blood-vessels, constituting the *glomerulus,* or *Malpighian corpuscles.*

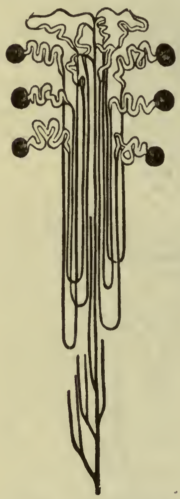

FIG. 14.—DIAGRAMMATIC EXPOSITION OF THE METHOD IN WHICH THE URINIFEROUS TUBES UNITE TO FORM PRIMITIVE CONES.—(*Tyson, after Ludwig.*)

Structure of the Tubules.—Each tubule consists of a basement membrane lined by epithelium cells throughout its entire extent. The tubule and its contained epithelium vary in shape and size in different parts of its course. The termination of the convoluted tube consists of a little sac or capsule, which is ovoid in shape and measures about $\frac{1}{200}$ of an inch. This capsule is lined by a layer of flattened epithelial cells, which is also reflected over the surface of the glomerulus. During the periods of secretory activity the blood-vessels of the glomerulus become filled with blood, so that the cavity of the sac is almost obliterated; after secretory activity the blood-vessels contract and the sac-cavity becomes enlarged. In that portion of the tubule lying between the capsule and Henle's loop the epithelial cells are cuboid in shape; in Henle's loop they are flattened, while in the remainder of the tubule they are cuboid and columnar.

Blood-vessels of the Kidney.—The *renal artery* is of large size and enters the organ at the hilum; it divides into several large branches, which penetrate the substance of the kidney between the pyramids, at the base of which they form an anastomosing plexus, which completely surrounds them. From this plexus vessels follow the straight tubes toward the apex of the pyramids, while others enter the cortical portion and pass to the surface. In the course of the latter, small branches are given off, each of which soon divides and subdivides to form a ball of capillary vessels known as the *glomerulus.* These capillaries, however, do not anastomose, but soon reunite to form an efferent vessel the caliber of which is less than that of the afferent artery. In consequence of this, there is a greater resistance to the outflow of blood than to the inflow, and, therefore, a higher blood-pressure in the glomerulus than in capillaries generally. The relation of the glomerulus to the tubule is important from a physiologic point of view. As stated above, the glomerulus is received into and surrounded by the terminal expansion or capsule of the tubule. This capsule, formed by an invagination of the terminal portion of the tubule, consists of two walls, an outer one consisting of an extremely thin basement membrane, covered by flattened epithelial cells, and an inner one consisting apparently only of flattened epithelium which is reflected over and closely invests the glomerular blood-vessels. The blood is thus separated from the interior of the capsule by the epithelial wall of the capillary and the epithelium of the reflected wall of the capsule. After its exit from the capsule the efferent vessel of the glomerulus soon again divides and subdivides to form an elaborate capillary plexus which surrounds and closely invests the convoluted tubules. From this plexus as well as from the plexus which surrounds the straight tubules veins arise which pass toward and empty into veins at the base of the pyramids. The renal vein formed by the union of these latter veins emerges from the kidney at the hilum and finally empties into the vena cava inferior.

The nerves to the kidney have their origin in the cells of small ganglia situated close to the semilunar ganglion. They pass to the kidney in the renal plexus and follow the course of the blood-vessels to their termination. The small renal ganglia are in connection with the spinal cord by means of the small splanchnics. The nerve fibers have both vaso-constrictor and vaso-dilatator functions.

The Renal Duct.—The renal duct, the **ureter,** is a membranous tube, situated behind the peritoneum about the diameter of a goose-quill, eighteen inches in length, and extends from the pelvis of the kidney to the base of the bladder, which it perforates in an oblique direction. It is composed of three coats: fibrous, muscle and mucous.

Mechanism of Urine Formation.—Inasmuch as the kidney presents (1) an apparatus for filtration, the capsule with its enclosed glomerulus, and (2) an apparatus for secretion, the tubule with its epithelium, it was originally inferred by Bowman that the elimination of the constituents of the urine from the blood is accomplished by the two-fold process of *filtration* and *secretion;* that the water and highly diffusible inorganic salts simply pass by diffusion through the walls of the blood-vessels of the glomerulus into the capsule of Müller, while the urea and remaining organic constituents are removed by true secretory action of the renal epithelium. Modern experimentation supports this view of renal action though subject to some modification.

The progress of physiologic investigation has confirmed the view that the capsule and glomerulus form a passive apparatus for the passage of a filtrate not merely of water and inorganic salts, but having the characteristics and composition of the blood plasma less its protein content. That the epithelium is not only a secretory apparatus removing organic constituents from the blood but is also an absorptive apparatus whereby water and inorganic salts may be returned to the blood when needed for nutritive purposes. The physical properties and chemic composition of urine are resultants of the coöperative action of these different factors.

The Influence of Blood Pressure.—The filtration of urinary constituents from the glomerulus into Müller's capsule depends largely upon the blood-pressure and the rapidity of blood flow in the renal artery and glomerulus.

The pressure of the blood in the glomeruli may be raised and the velocity increased:

1. By an increase in blood-pressure generally.
2. By an increase in the pressure of the renal artery alone.

The first condition may be brought about by an increase in either the force or frequency of the heart's action or by a contraction of the arterioles of vascular areas in any or all parts of the body, excepting, of course, the renal vascular area. The second condition is brought about by a dilatation of the renal artery alone and possibly by a contraction of the efferent vessels of the glomeruli.

The pressure of the blood in the glomeruli may be diminished and the velocity decreased:

1. By a decrease in the blood-pressure generally.
2. By a decrease in the pressure of the renal artery alone.

The first condition is brought about by a decrease in either the force or frequency of the heart's action or by a dilatation of the arterioles of large vascular areas in any or all parts of the body. The second condition is brought about by contraction of the renal artery alone and possibly by a dilatation of the efferent vessels of the glomeruli. Coincident with the rise and fall of pressure in the glomerular capillaries there is a rise and fall in the rate of urinary flow.

The Storage and Discharge of Urine.—Urination.—The urinary constituents, as soon as they are eliminated from the blood, pass into and through the uriniferous tubules and by them are discharged into the pelvis of the kidney. They then enter the ureter by which they are conducted to the bladder. The immediate cause of this movement is undoubtedly a difference of pressure between the terminal portions of the tubules and the terminal portion of the ureter, aided by the peristaltic contraction of the muscle wall of the ureter.

The Bladder.—The bladder is a reservoir for the reception and temporary storage of the urine prior to its expulsion from the body; when fully distended it is ovoid in shape, and holds from 600 to 800 c.c. It is composed of four coats; *serous*, *muscle* (the fibers of which are arranged longitudinally and circularly), *areolar*, and *mucous*. The orifice of the bladder is controlled by the *sphincter vesicæ*, a muscular band about ½ of an inch in width. The muscle-fibers collectively constitute the detrusor urinæ muscle.

Nerve Mechanism of Urination.—When the urine has passed into the bladder, it is there retained by the sphincter vesicæ muscle, kept in a state of tonic contraction by the action of a nerve center in the lumbar region of the spinal cord. This center can be inhibited and the sphincter relaxed, either *reflexly*, by impressions coming through sensory nerves from the mucous membrane of the bladder, or *directly*, by a voluntary impulse descending the spinal cord. When the desire to urinate is experienced, impressions made upon the vesical sensory nerves are carried to the centers governing the *sphincter* and *detrusor urinæ* muscles and to the brain. If now the act of urination is to take place, a voluntary impulse originating in the brain passes down the spinal cord and still further inhibits the sphincter vesicæ center, with the effect of relaxing the muscle and of stimulating the center governing the detrusor muscle, with the effect of contracting the muscle and expelling the urine. If the act is to be suppressed, voluntary impulses inhibit the *detrusor* center and possibly stimulate the *sphincter* center.

The *genitospinal* center controlling these movements is situated in that portion of the spinal cord corresponding to the origin of the third, fourth, and fifth sacral nerves.

SKIN

The Skin.—The skin, the external investment of the body, is a most complex and important structure, serving—

1. As a *protective covering*.
2. As an organ for *tactile sensibility*.
3. As an organ for the *elimination of excrementitious matters*.

The **amount of skin** investing the body of a man of average size is about twenty feet, and varies in thickness, in different situations, from 1/8 to 1/100 of an inch.

The skin consists of two principal layers—viz., a deeper portion, the *corium*, and a superficial portion, the *epidermis*.

The Corium.—The corium, or cutis vera, may be subdivided into a *reticulated* and a *papillary layer*. The *former* is composed of white fibrous tissue, non-striated muscle-fibers, and elastic tissue, interwoven in every direction, forming an areolar network, in the meshes of which are deposited masses of fat, and a structureless, amorphous matter; the *latter* is formed mainly of club-shaped elevations or projections of the amorphous matter, constituting the *papillæ;* they are most abundant and well developed under the palms of the hands and upon the soles of the feet; they average 1/100 of an inch in length, and may be simple or compound; they are well supplied with nerves, blood-vessels, and lymphatics.

The Epidermis.—The epidermis, or scarf skin, is an extravascular structure, a product of the true skin, and is composed of several layers of cells. It may be divided into two layers: the *rete mucosum*, or the *Malpighian layer*, and the *horny* or *corneous*.

The *former* is closely adherent to the papillary layer of the true skin, and is composed of large nucleated cells, the lowest layer of which, the "prickle cells," contains pigment-granules, which give to the skin its varying tints in different individuals and in different races of men; the more superficial cells are large, colorless, and semi-transparent. The *latter*, the corneous layer, is composed of flattened cells, which, from their exposure to the atmosphere, are hard and horny in texture; it varies in thickness from 1/8 of an inch on the palms of the hands and soles of the feet to 1/600 of an inch in the external auditory canal.

Appendages of the Skin.—**Hairs** are found in almost all portions of the body, and can be divided into—

1. Long, soft hairs, on the head.
2. Short, stiff hairs, along the edges of the eyelids and nostrils.
3. Soft, downy hairs on the general cutaneous surface.

They consist of a *root* and a *shaft*. The latter is oval in shape and about 1/400 of an inch in diameter; it consists of fibrous tissue, covered externally by a layer of imbricated cells, and internally by cells containing granular and pigment material.

The root of the hair is embedded in the hair-follicle, formed by a tubular depression of the skin, extending nearly through to the subcutaneous tissue; its walls are formed by the layers of the corium, covered by epidermic cells. At the bottom of the follicle is a papillary projection of amorphous matter, corresponding to a papilla of the true skin, containing blood-vessels and nerves, upon which the hair-root rests. The investments of the hair-roots are formed of epithelial cells, constituting the *internal* and *external* root-sheaths.

The hair protects the head from the heat of the sun and from the cold, retains the heat of the body, prevents the entrance of foreign matter into the lungs, nose, ears, etc. The *color* is due to pigment matter. In old age the hair becomes more or less whitened.

The Sebaceous Glands.—The sebaceous glands, embedded in the true skin, are simple and compound racemose glands, opening, by a common excretory duct, upon the surface of the epidermis or into the hair-follicle. They are found in all portions of the body, most abundantly in the face, and are formed by a delicate, structureless membrane, lined by flattened polyhedral cells. The sebaceous glands secrete a peculiar oily matter (the *sebum*), by which the skin is lubricated and the hairs are softened; it is quite abundant in the region of the nose and forehead, which often presents a greasy, glistening appearance; it consists of water, mineral salts, fatty globules, and epithelial cells.

The *vernix caseosa*, which frequently covers the surface of the fetus at birth, consists of the residue of the sebaceous matter, containing epithelial cells and fatty matters; it seems to keep the skin soft and supple, and guards it from the effects of the long-continued action of the amniotic water.

The Sudoriparous Glands.—The sudoriparous glands excrete the sweat. They consist of a mass or coil of a tubular gland duct, situated in the derma and in the subcutaneous tissue, average $\frac{1}{75}$ of an inch in diameter, and are surrounded by a rich plexus of capillary blood-vessels. From this oil the duct passes in a straight direction up through the skin to the epidermis, where it makes a few spiral turns and opens obliquely upon the surface. The sweat-glands consist of a delicate homogeneous membrane lined by epithelial cells, whose function is to extract from the blood the elements existing in the perspiration.

The glands are very abundant all over the cutaneous surface—as many as 3,528 to the square inch, according to Erasmus Wilson.

The **perspiration** is an excrementitious fluid, clear, colorless, almost odorless, slightly acid in reaction, with a specific gravity of 1,003 to 1,004.

The **total quantity** of perspiration excreted daily has been estimated at about two pounds, though the amount varies with the nature of the food and drink, exercise, external temperature, season, etc.

The elimination of the sweat is not intermittent, but continuous: it takes place so gradually that as fast as it is formed it passes off by evaporation as *insensible* perspiration. Under exposure to great heat and exercise the evaporation is not sufficiently rapid, and it appears as *sensible* perspiration.

COMPOSITION OF SWEAT

Water	995.573
Urea	0.043
Fatty matters	0.014
Alkaline lactates	0.317
Alkaline sudorates	1.562
Inorganic salts	2.491
	1,000.000

Urea is a constant ingredient.

Carbonic acid is also exhaled from the skin, the amount being about $\frac{1}{200}$ of that from the lungs.

Prespiration regulates the temperature and removes waste matters from the blood; it is so important that if elimination be prevented, death occurs in a short time.

Influence of the Nerve System.—The secretion of sweat is regulated by the nerve system. Here, as in the secreting glands, the fluid is formed from material in the lymph-spaces surrounding the gland. Two sets of nerves are concerned—viz.: *vasomotor*, regulating the blood-supply; and *secretor*, stimulating the activities of the gland cells. Generally the two conditions, increased blood flow and increased glandular action, coexist. At times profuse clammy perspiration occurs, with diminished blood flow. Sweat centers are found in the spinal cord between the levels of the second thoracic and third lumbar nerves. The secretory fibers reach the perspiratory glands of the head and face through the cervical sympathetic; of the arms, through the thoracic sympathetic, ulnar, and radial nerves; of the leg, through the abdominal sympathetic and sciatic nerves. The course they pursue is similar to those of the vasomotor nerves with which they are associated.

The sweat-center is excited to action by mental emotions, increased temperature of blood circulating in the medulla and cord, increased venosity of blood, many drugs, rise of external temperature, exercise, etc.

EXTERNAL SECRETIONS

Secretion is a term applied to a process by which complex fluids are formed from the constituents of the lymph which are separated from the blood-stream by the activities of the endothelial cells of the capillary wall, as the blood flows through the capillary blood-vessels.

These separated materials may be utilized in several ways:

1. For the repair of the tissues, for growth, for the liberation of energy.

2. For the elaboration or production by specialized organs of a variety of complex fluids and specific materials, of widely different application. The fluids and specific materials thus formed are utilized for the most part to meet some special need of the body. All such fluids and materials are termed *secretions*, and the organs by which they are formed are termed secretor organs. Secretions whether simple or complex may in a general way be divided into two groups, viz.: external and internal.

External Secretions.—An external secretion may be defined as a more or less complex fluid formed by the secretor activities of epithelial cells of glands, which is discharged through well-defined ducts on the surfaces of the body, the skin or mucous membrane. The glands by which they are formed or secreted are known as glands of *external* secretion.

Internal Secretions.—Internal secretions may be defined as more or less complex materials or agents formed by the activities of epithelial cells of organs, and which are discharged into, and distributed by the blood to organs and tissues near and remote, the activities of which they influence in varying ways and degrees. The glands by which they are formed or secreted are known as glands of *internal* secretion.

Organs of External Secretions.—All organs belonging to this group consist primarily of a thin delicate homogeneous membrane, one side of which is covered with a layer of epithelial cells and the other side of which is closely invested by a network of capillary blood-vessels, lymph-vessels, and nerves. Though the epithelial cells have a general histologic resemblance one to another, their physiologic function varies in different situations, in accordance probably with their ultimate chemic structure, a fact which determines the difference in the character of the secretions.

These organs may consist of a single layer of cells or a group of cells, and may be subdivided into—

1. Secreting membranes.
2. Secreting glands.

The **secreting membranes** are the mucous membranes lining the gastro-intestinal, the pulmonary, and the genito-urinary tracts. The **secreting glands** are formed of the same histologic elements as the secreting membranes. They are formed by an involution of the mucous membrane or skin, the epithelium of which is variously modified structurally and functionally in the various situations in which they are formed. Like the membranes themselves, the glands are invested by capillary blood-vessels and supplied with lymph-vessels and nerves, of which the latter are in direct connection with the blood-vessels and epithelial cells. The interior of each gland is in communication with the free surface by one or more passageways known as ducts.

These glands may be classified according as the involution is cylindrical or dilated as—

1. Tubular. The *tubular* glands may be simple—*e.g.*, sweat-glands, intestinal glands, fundus glands of the stomach; or compound—*e.g.*, kidney, testicle, salivary, and lachrymal glands.

2. Alveolar. The *alveolar* glands may also be simple—*e.g.*, the sebaceous glands, the ovarian follicles, meibomian glands; or compound, as the mammary glands and salivary glands.

In the production of the secretion two essentially different processes are concerned:

1. *Chemic.*—The formation and elaboration of the characteristic organic ingredients of the secreted fluids—*e.g.*, pepsin, pancreatin—take place during the intervals of glandular activity, as a part of the general function of nutrition. They are formed by the cells lining the glands, and can often be seen in their interior with the aid of the microscope—*e.g.*, bile in the liver-cells, fat in the cells of the mammary gland.

2. *Physical.*—Consisting of a transudation of water and mineral salts from the blood into the interior of the gland.

During the intervals of glandular activity only that amount of blood passes through the gland sufficient for proper nutrition; when the gland begins to secrete, under the influence of an appropriate stimulus, the blood-vessels dilate and the quantity of blood becomes increased beyond that flowing to the gland during its repose.

Under these conditions a transudation of water and salt takes place, washing out the characteristic ingredients, which are discharged by the gland ducts. The *discharge* of the secretion is intermittent; they are retained in the glands until they receive the appropriate stimulus, when they pass into the larger ducts by the *vis a tergo*, and are then discharged by the contraction of the muscular walls of the ducts.

The *activity* of glandular secretion is hastened by an increase in the blood-volume and pressure and retarded by a diminution.

The Influence of the Nerve System.—The activity of every gland is controlled by nerve-centers situated in the central nerve-system. These centers may be excited to activity either by impressions made on the peripheral terminations of afferent nerves or by emotional states; or, possibly, by changes in the composition of the blood itself. As a rule, all normal secretion is a reflex act involving the usual mechanism, viz.: a receptive surface (skin, mucous membrane, or sense-organ), an afferent nerve, an emissive cell from which emerges an efferent nerve to be distributed to a responsive organ, the gland epithelium, though the secretion may in some instances be initiated by a psychic state.

The structure of the glands of external secretion, the composition and physiologic actions of their secretions have in large part been considered in the foregoing chapter on Digestion. There remains, however, to be considered the mammary glands, the liver and the sebaceous glands.

MAMMARY GLANDS

The **mammary glands,** which secrete the milk, are two more or less hemispheric organs, situated in the human female on the anterior surface of the thorax. Though rudimentary in childhood, they gradually increase in size as the young female approaches puberty.

The gland presents at its convexity a small prominence of skin (the nipple) which is surrounded by a circular area of pigmented skin (the areola). The gland proper is covered by a layer of adipose tissue anteriorly and is attached posteriorly to the pectoral muscles by a meshwork of fibrous tissue. During utero-gestation the mammary glands become larger, firmer, and more lobulated; the areola darkens and the veins become more prominent. At the period of lactation the gland is the seat of active histologic and physiologic changes, correlated with the production of milk. At the close of lactation the glands diminish in size, undergo involution, and gradually return to their original non-secreting condition.

Structure of the Mammary Gland.—The mammary gland consists of an aggregation of some fifteen or twenty lobes, each of which is surrounded by a framework of fibrous tissue. The lobe is provided with an excretory duct, which, as it approaches the base of the nipple, expands to form a sinus or reservoir, beyond which it opens by a narrowed orifice on the surface of the nipple. On tracing the duct into a lobe, it is found to divide and subdivide, and finally to terminate in lobules or acini. Each acinus consists of a basement membrane, lined by low polyhedral cells. Externally it is surrounded by connective tissue supporting blood-vessels, lymphatics and nerves.

MILK

Milk is an opaque, bluish-white fluid, almost inodorous, of a sweet taste, an alkaline reaction, and a specific gravity of 1,025 to 1,040. When examined microscopically it is seen to consist of a clear fluid (the *milk-plasma*), holding in suspension an enormous number of small, highly refractive oil-globules, which measure, on an average, 1/100,000 of an inch in diameter. Each globule is supposed by some observers to be surrounded by a thin, albuminous envelope, which enables it to maintain the discrete form. *The quantity* of milk secreted daily by the human female averages about two and a half pints. The milk of all mammalia consists of all the different classes of nutritive principles, though in varying proportions. The relative proportions in which these constituents exist are shown in the following table of analyses:

THE COMPOSITION OF MILK

Constituents	Human	Cow	Goat	Mare	Ass
Water	87.80	87.00	86.91	90.00	90.00
Caseinogen / Lactalbumin	1.50	3.20	3.69	1.80	2.10
Fat	3.50	3.80	4.09	1.30	1.30
Lactose	7.00	5.00	4.45	5.50	6.30
Inorganic Salts	0.20	0.50	0.86	0.30	0.30

Caseinogen is the chief protein constituent of milk, and is held in solution by the presence of calcium phosphate. On the addition of acetic acid or of sodium chlorid up to the point of saturation, the caseinogen is *precipitated* as such, and may be collected by appropriate chemic methods. When taken into the stomach caseinogen is *coagulated*—that is, it is separated into casein or tyrein and a small quantity of a new soluble protein. The ferment which induces this change is known as rennin. The presence of calcium phosphate is necessary for this coagulation.

Fat is present in the condition of a fine emulsion and is more or less solid at ordinary temperatures. It is a composition of olein, palmitin, and stearin, with a small quantity of butyrin and caproin. When milk is allowed to stand for some time the fat-globules rise to the surface and form a thick layer, known as cream. When subjected to the churning process, the fat globules run together and form a cohesive mass—the butter.

Lactose is the particular form of sugar characteristic of milk. It belongs to the saccharose group and has the following composition: $C_{12}H_{22}O_{11}$. In the presence of the *Bacilus acidi lactici* the lactose is in part reduced to lactic acid and carbon dioxid, the former of which will cause a precipitation of the caseinogen. It is the presence of lactic acid that imparts the sour taste to milk.

Inorganic salts are always present and are chiefly those of potassium, sodium, calcium, and magnesium, phosphates and chlorids.

Iron is also present in small amounts possibly from 3 to 5 milligrams per 1,000 c.c. Citric acid to the extent of 0.05 per cent. is also present.

Mechanism of Secretion.—During the time of lactation the mammary gland exhibits periods of secretory activity which alternate with periods of rest. Coincidently with these periods, certain histologic changes take place in the secreting structures of the gland. At the close of a period of active secretion each acinus presents the following features: the epithelial cells are short, cubic, nucleated, and border a relatively wide lumen in which is to be found a variable quantity of non-discharged milk. After the gland has rested for some time, active metabolism again begins. The epithelial cells grow and elongate; the nucleus divides into two or three new nuclei, and at the same time the cell becomes constricted; the inner portion is detached and is discharged into the lumen. Coincidentally with these changes oil-globules make their appearance in the cell protoplasm, some of which are discharged separately into the lumen, while others remain for a time associated with the detached cell. From these histologic changes it would appear that the caseinogen and the fat-globules are metabolic products of the cell protoplasm, and not derived directly from the blood. That lactose has a similar origin appears certain from the fact that it is formed independently of carbohydrate food. The water and inorganic salts are doubtless secreted by a mechanism similar to that of all other secreting glands.

Colostrum.—Within a day or two after parturition the alveoli become filled with a fluid which in some respects resembles milk and which has been termed colostrum. This is a watery fluid containing disintegrated epithelial cells and fat-globules, as well as colostrum corpuscles, which are probably leukocytes containing fine fat-globules. Colostrum is distinguished from milk in being richer in sugar and inorganic salts. It also differs from milk in undergoing coagulation by heat which is supposed to be due to the presence of a globulin. Its coagulation point is about 72°C. It is said to possess constituents which act as a laxative to the young child.

LIVER

The **liver** is a highly vascular, conglomerate gland, appended to the alimentary canal. It is the largest gland in the body, weighing about four and one-half pounds; it is situated in the right hypochondriac region, and is retained in position by five ligaments, four of which are formed by duplicatures of the peritoneal investment.

The *proper coat* of the liver is a thin but firm fibrous membrane, closely adherent to the surface of the organ, which it penetrates at the transverse fissure, and follows the vessels in their ramifications through its substance, constituting *Glisson's capsule.*

Structure of the Liver.—The liver is made up of a large number of small bodies (the *lobules*), rounded or ovoid in shape, measuring $\frac{1}{25}$ of an inch in diameter, separated by a space in which are situated blood-vessels, nerves, hepatic ducts, and lymphatics.

The **lobules** are composed of cells, which, when examined microscopically, exhibit a rounded or polygonal shape, and measure, on the average, $\frac{1}{1000}$ of an inch in diameter; they possess one, and sometimes two, nuclei; they also contain globules of fat, pigment matter, and animal starch. The cells constitute the *secreting* structure of the liver, and are the *true hepatic cells.*

The Blood-vessels.—The blood-vessels which enter the liver are:

1. The *portal vein*, made up of the *gastric*, *splenic*, and *superior* and *inferior mesenteric veins.*
2. The *hepatic artery,* a branch of the celiac axis.

Both the portal vein and the hepatic artery are invested by a sheath of areolar tissue.

The vessels which leave the liver are the *hepatic veins*, originating in its interior, collecting the blood distributed by the portal vein and hepatic artery, and conducting it to the *ascending vena cava.*

Distribution of Vessels.—The *portal vein* and the *hepatic artery*, upon entering the liver, penetrate its substance, divide into smaller and smaller branches, occupy the spaces between the lobules, completely surrounding and limiting them, and constitute the *interlobular* vessels. The *hepatic artery*, in its course, gives off branches to the walls of the portal vein and Glisson's capsule, and finally empties into the small branches of the *portal vein* in the interlobular spaces.

The *interlobular vessels* form a rich plexus around the lobules, from which branches pass to neighboring lobules and enter their substance, where they form a very fine net work of capillary vessels, ramifying over the hepatic cells, in which the various functions of the liver are performed. The blood is then collected by small veins, converging toward the center of the lobule, to form the *intralobular vein*, which runs through its long axis and empties into the *sublobular vein*. The *hepatic veins* are formed by the union of the sublobular veins, and carry the blood to the ascending vena cava; their walls are thin and adherent to the substance of the hepatic tissue.

Bile Capillaries and Hepatic Ducts.—The bile capillaries are narrow channels which penetrate the lobule in all directions and are generally found running along the sides of the cells. These channels, which are devoid of walls, receive from the cells some of the products of their secretor activity, and hence are comparable to the lumen of the alveoli of other secreting glands. At the periphery of the lobules the bile capillaries communicate with large channels which are the beginnings of the hepatic or bile-ducts lying in the interlobular spaces. The interlobular bile-ducts possess a distinct wall lined by flattened epithelium. There is, however, no distinct line of demarcation between the cells of the interlobular ducts and the secreting cells of the liver proper, as the two blend insensibly, the one into the other. As the hepatic ducts increase in size they gradually acquire the structure characteristic of the main hepatic duct: viz., a mucous, a muscle, and a fibrous coat. Two ducts emerge from the liver which after a short course unite to form the main hepatic duct. The **main hepatic** emerges from the liver at the transverse fissure. At a distance of about 5 centimeters it is joined by the cystic duct, the distal extremity of which expands into a pear-shaped reservoir—the *gall-bladder* in which a portion of the bile is temporarily stored. The duct formed by the union of the hepatic and cystic ducts—the common bile duct passes forward for a distance of about 7 centimeters and opens into the duodenum.

Functions of the Liver.—The liver is a complex organ having a variety of relations to the general processes of the body. While its physiologic actions are not yet wholly understood, it may be said that it is engaged:

1. In the secretion of bile.
2. In the production of starch (glycogen) and sugar (glucose).
3. In the formation of urea.
4. In the conjugation of products of protein putrefaction.

The Secretion of Bile.—The characteristic constituents of the bile do not preëxist in the blood, but are formed in the interior of the liver cells of materials derived from the venous and arterial blood. The hepatic cells, absorbing these materials, elaborate them into bile-elements, and in so doing undergo histologic changes similar to those exhibited by other secretory glands. The bile once formed, it passes into the mouths of the bile capillaries, near the periphery of the lobules. Under the influence of the *vis a tergo* of the new-formed bile it flows from the smaller into the large bile-ducts, and finally empties into the intestine, or is regurgitated into the gall-bladder, where it is stored up until it is required for the digestive process in the small intestine. The study of the secretion of bile by means of biliary fistulæ reveals the fact that the secretion is continuous and not intermittent; that the hepatic cells are constantly pouring bile into the ducts, which convey it into the gall-bladder. As this fluid is required only during intestinal digestion, it is only then that the walls of the gall-bladder contract and discharge it into the intestine.

The flow of bile from the liver cells into the gall-bladder is accomplished by the inspiratory movements of the diaphragm, and by the contraction of the muscle-fibers of the biliary ducts, as well as the pressure of new-formed bile. Any obstacle to the outflow of bile into the intestine leads to an accumulation within the bile-ducts. The pressure within the ducts increasing beyond that of the blood within the capillaries, a reabsorption of biliary matters by the lymphatics takes place, giving rise to the phenomena of jaundice.

The **bile** is both a *secretion* and an *excretion;* it contains new constituents, which are formed only in the substance of the liver, and are destined to play an important part ultimately in nutrition; it contains also waste ingredients, which are discharged into the intestinal canal and eliminated from the body.

The Production of Glycogen and Sugar.—In addition to the preceding function, Bernard, in 1848, demonstrated the fact that the liver, during life, normally produces a substance analogous in its chemic composition to starch, which he termed glycogen; also that, when the liver is removed from the body, and its blood-vessels are thoroughly washed out, after a few hours sugar makes its appearance in abundance. The sugar can also be shown to exist in the blood of the hepatic vein as well as in a decoction of the liver substance by means of either Trommer's or Fehling's test, even when the blood of the portal vein does not contain a trace of sugar.

Origin and Destination of Glycogen.—Glycogen appears to be formed in the liver cells, from materials derived from the food, whether the diet be animal or vegetable, though a larger percentage is formed when the animal is fed on starchy and saccharine than when fed on animal food. The *dextrose*, which is one of the products of digestion, is absorbed by the blood-vessels and carried directly into the liver; as it does not appear in the urine, as it would if injected at once into the general circulation, it is probable that it is detained in the liver, dehydrated, and stored up as *glycogen.* The change is shown by the following formula:

$$\underset{\text{Dextrose.}}{C_6H_{12}O_6} - \underset{\text{Water.}}{H_2O} = \underset{\text{Glycogen.}}{C_6H_{10}O_5}.$$

The glycogen thus formed is stored up in the hepatic cells for the future requirements of the system. When sugar is needed for nutritive purposes, the glycogen is transformed into *dextrose* by the agency of a ferment.

Glycogen, when obtained from the liver, is an amorphous, starch-like substance, of a white color, tasteless and colorless, and soluble in water; by boiling with dilute acids, or subjected to the action of an animal ferment, it is easily converted into *dextrose.* When an excess of sugar is generated by the liver out of the glycogen, dextrose can be found not only in the blood of the hepatic vein, but also in other portions of the vascular apparatus.

The Formation of Urea.—The liver is now regarded by many physiologists as the principal organ concerned in urea formation.

The antecedent of the urea, the substances out of which the liver cells form urea, are for the most part the ammonium salts, the carbonate and carbamate, which are brought to the liver by the blood of the portal vein. These salts are formed largely in the intestinal wall out of the amino acids that result from the digestion of proteins. It is also very probable that they arise from the disintegration of amino-acids in other portions of the body.

The Conjugation of Products of Protein Putrefaction.—One of the important functions of the liver is the conversion of toxic compounds, the products of the putrefaction of proteins, into non-toxic compounds. These compounds are formed in the intestine, are absorbed and carried by the blood of the portal vein to the liver. In their passage through the capillaries of the liver they are conjugated for the most part with potassium sulphate by the action of the liver cells and thus deprived of their toxicity. Among the substances thus conjugated are indol, skatol, phenol, and cresol. After absorption indol and skatol are oxidized to indoxyl and skatoxyl and then combined with potassium sulphate giving rise to potassium indoxyl sulphate and potassium skatoxyl sulphate. Phenol and cresol are apparently directly combined with potassium sulphate. All of these compounds then pass into the blood of the general circulation and finally are eliminated by the kidneys. Potassium indoxyl sulphate or indican is the source of the indigo-forming substance found in the urine. Other compounds are like-wise reduced in toxicity by the liver cells though the methods by which this is accomplished vary with the nature of the compound. The liver thus presents a chemic defense against the entrance of more or less toxic agents into the blood of the general circulation.

INTERNAL SECRETIONS

An internal secretion may be defined as a more or less complex material or agent, produced by the secretor activities of epithelial cells of organs and tissues, and which are discharged into the blood and distributed to organs more or less remote, the activities of which they influence in varying ways and degrees. Some increase, some inhibit physiologic processes while others stimulate growth and in different ways modify metabolism. The internal secretion in many, if not all instances belongs to a class of agents known as *hormones*, agents of known or unknown composition, characterized by a relatively simple chemic or molecular composition, an easy diffusibility across the walls of the capillary blood-vessels, a ready susceptibility to oxidation and a rapid elimination, as a result of which, their action does not continue indefinitely.

Glands of Internal Secretion or Endocrinous Glands.—The glands consist mainly of epithelial cells in close relation to the walls of capillary blood-vessels and lymphatics, and in some instances, if not all, under the control of the central nerve system. By reason of the absence of ducts and their relation to blood-vessels they have also been termed *ductless* glands and *vascular* glands and inasmuch as the secretion is discharged internally (into the blood) they have been designated *endocrinous* glands.

The glands which fall into this category are the thyroid, the parathyroids, the adrenals, the hypophysis cerebri or pituitary, the pancreas, the ovaries and testicles.

Thyroid Gland.—The thyroid gland or body consists of two lobes situated on the lateral aspect of the upper part of the trachea. Each lobe is pyriform in shape, the base directed downward and on a level with the fifth or sixth tracheal ring. The lobe is about 50 mm. in length, 20 mm. in breadth, and 25 mm. in thickness. As a rule, the lobes are united by a narrow band or isthmus of the same tissue. In color the gland is reddish, and it is abundantly supplied with blood-vessels and lymphatics.

Microscopic examination shows that the thyroid consists of an enormous number of closed sacs or vesicles, variable in size, the largest not measuring more than 0.1 mm. in diameter. Each sac is composed of a thin homogeneous membrane lined by cuboid epithelium. The interior of the sac in adult life contains a transparent viscid fluid, containing albumin and termed "colloid" substance. Externally, the sacs are surrounded by a plexus of capillary blood-vessels and lymphatics. The individual sacs are united and supported by connective tissue, which forms, in addition, a covering for the entire gland. The knowledge at present possessed as to the function of the thyroid gland, especially in mammals, is the outcome of a study of the effects which follow its arrest of development in the child, its degeneration in the adult, its extirpation in the human being as well as in animals.

Congenital absence of the gland or its *arrested development* in early childhood is followed by a defective physical and mental development characterized by the group of phenomena termed *cretinism.*

Degenerative processes which arise in the thyroid in the adult give rise to a group of phenomena to which the term *myxedema* has been given. The most striking of these phenomena is a swollen condition of the skin, the result of hyperplasia of the subcutaneous connective tissue of an embryonic type, rich in *mucin.* Partly in consequence of this change in the skin the face becomes broader, swollen and flattened with a loss of expression. With the progress of the degeneration, the mind becomes dull and clouded, the memory defective and finally the condition of idiocy may be established.

Surgical removal of the thyroid when complete, for relief from symptoms due to grave pathologic changes, has been followed in human beings by symptoms similar, if not identical with those of myxedema. To this condition the terms operative myxedema and cachexia strumipriva have been applied. Removal of the gland from animals is followed by the same symptoms and death in from two to three weeks. From these facts it is evident that the presence of the thyroid is essential to the normal activity of the tissues generally. As to the manner in which it exerts its favorable influence, there is some difference of opinion. The view that the gland removes from the blood certain toxic bodies, rendering them innocuous, and thus preserving the body from a species of auto-intoxication, is gradually yielding to the more probable view that the epithelium is engaged in the secretion of a specific material, which finds its way into the blood or lymph and in some unknown way influences favorably tissue metabolism. This view of the function of the thyroid is supported by the fact that successful grafting of a portion of the thyroid beneath the skin or in the abdominal cavity will prevent the usual symptoms which follow thyroidectomy. The same result is obtained by the intravenous injection of thyroid juice or by the administration of the raw gland. The retention of a small portion of the gland when it is removed by surgical means will prevent the occurrence of operative myedema.

Hyperthyroidism, a condition characterized by vertigo, increased cardiac action, flushing, tremors, glycosuria, and in monkeys, exophthalmos and a widening of the palpebral fissure, may be developed by the administration of large doses of the gland extracts. From these facts the inference has been drawn from the clinical side that the symptoms comprised under the term exophthalmic goiter, viz.: rapid action of the heart, pulsation of the large arteries at the base of the neck, protrusion of the eyeballs and fine tremors of the hands, are due to an enlargement of the gland and a hypersecretion of the thyroid cells, a condition spoken of as *hyperthyroidism*. This inference has apparently been confirmed by the disappearance of the symptoms after the removal of a large portion of the gland, care being taken to leave a small portion sufficiently large, however, to produce the necessary amount of the internal secretion.

The Thyroid Secretion.—The chemic features of the material secreted and obtained from the structures of the thyroid indicate that it is a complex protein containing iodin, which, under the influence of various reagents, undergoes cleavage, giving rise to a non-protein residue, which carries with it the iodin and phosphorus. The amount of iodin in the thyroid varies from 0.33 to 1 milligram for each gram of tissue. To this compound the term *thyro-iodin* has been given. The administration of this compound produces effects similar to those which follow the therapeutic administration of the fresh thyroid itself, viz.: a diminution of all myxedematous symptoms. In normal states of the body, *thyro-iodin* influences very actively the general metabolism. It gives rise to a decomposition of fats and proteins and to a decline in body-weight. In large doses it may produce toxic symptoms, *e.g.*, increased cardiac action, vertigo, and glycosuria.

The Function of the Thyroid Gland.—The function or the physiologic action of the thyroid gland itself is to produce an internal secretion which after its entrance into the blood promotes favorably the metabolism of the neuro-muscular systems at least. The myxedema and the failure of the mental powers are attributed to the loss or degeneration of the gland and hence its internal secretion, and cretinism to the arrest of its development.

The Parathyroids.—The parathyroids are small bodies, usually four in number, two on each side. They are divided into superior and inferior. The superior are situated internally and on the posterior surface in close relation to, and frequently embedded in, the substance of the thyroid; the inferior are situated externally, sometimes in contact with, and at other times removed a variable distance from the thyroid.

Microscopically the parathyroids consist of thick cords of epithelial cells separated by septa of fine connective tissue and surrounded by capillary blood-vessels. Chemic analysis shows that they also contain iodin in combination with some organic compound.

Effects of Parathyroid Removal.—The surgical removal of the parathyroids is followed in the course of from two to five days by the death of the animal preceded in most instances by a series of symptoms which are embraced under the general term "tetany." These symptoms are fibrillary contractions of muscles, tremors, spasmodic contractions and paralyses of groups of muscles and not infrequently convulsive seizures and coma. During the convulsion there is an acceleration of the heart-beat, and increase in the respiratory movements which frequently become dyspneic in character. There is also a loss of appetite, nausea, mucous vomiting, and diarrhea. Death may occur during a convulsion or from coma. (Morat and Doyon.)

These results for the most part occur only when all the parathyroids are removed. It is asserted that even if one gland is retained the animal does not die. The above described symptoms may manifest themselves, however, but they are slight in degree.

The Hypophysis Cerebri.—This is a small body lodged in the sella turcica of the sphenoid bone. It consists of an anterior lobe, somewhat red in color, and a posterior lobe, yellowish-gray in color. The former is much the larger and partly embraces the latter. The anterior lobe is developed from an invagination of the epiblast of the mouth cavity, and consists of distinct gland tissue. The posterior lobe is an outgrowth from the brain and is connected with the infundibulum by a short stalk. It has been suggested that the term infundibular body be reserved for the posterior lobe. This distinction appears to be desirable, inasmuch as in their origin and structure they are separate and distinct bodies.

Complete removal of the hypophysis cerebri, or the pituitary body, is always followed by a fatal result, preceded by symptoms not unlike those which follow removal of the thyroid: viz., unsteadiness of gait, muscular twitchings, lethargy, fall of blood pressure, lowering of the body temperature, coma and death.

Partial removal of the *anterior lobe* is much less fatal, though adult animals become adipose and degenerate sexually. Young animals remain undersized and fail to develop sexual characteristics. Sexual infantilism persists. From these and similar facts it has been assumed that sexual infantilism is due to defective activity of the anterior lobe. Hyperactivity of the anterior lobe in early life may lead to giantism and in the adult to acromegaly.

Removal of the *posterior lobe* leads to an increased tolerance for and assimilation of sugar which eventually contributes to the formation and deposition of fat. On the contrary a hyperactivity of the posterior lobe leads to a diminished tolerance for sugar as shown by the appearance of hyperglycemia and glycosuria. The internal secretion of the posterior lobe is believed to be the hyaline granules which, streaming through the lobe, are discharged into the third ventricle.

Intravenous injection of pituitary extracts or the pharmaceutical preparation *pituitrin* is followed by a rise of blood pressure from a contraction of the arteriole muscles, and an inhibition of the heart. It also causes dilatation of the renal vessels and stimulates specifically the renal cells to activity, thus causing a marked diuresis. The extract also stimulates the non-striated muscles of the intestines, bladder, uterus, mammary glands, as well as the dilatator muscle of the iris.

The Functions of the Pituitary or Hypophysis.—The functions of the pituitary body are related to the activities of the anterior and posterior lobes. The anterior lobe, through its internal secretion, stimulates the growth of the skeleton and associated tissues as apparently shown by the fact that an excess of secretion in early life leads to giantism and in adult life to acromegaly, while a deficiency of secretion leads to defective growth and the establishment of infantilism. The posterior lobe through its internal secretion assists in the regulation of carbohydrate metabolism as shown by the fact that an excess of secretion lowers the assimilation capacity and thus develops glycosuria, while a deficiency of the secretion raises the assimilation capacity and leads to the production and accumulation of fat.

Adrenal Bodies, or Suprarenal Capsules.—These are two flattened bodies, somewhat crescentic or triangular in shape, situated each upon the upper extremity of the corresponding kidney, and held in place by connective tissue. They measure about 40 mm. in height, 30 mm. in breadth, and from 6 to 8 mm. in thickness. The weight of each is about 4 gm.

Histology.—The gland is covered externally by a fibrous tissue from which septa pass into the more central portions thus forming a framework for the support of blood-vessels and cells.

A section of the gland shows just beneath the capsule an outer portion termed the *cortex* and an inner portion termed the *medulla*. The cortex consists mainly of cuboid cells arranged in cylindric columns. The outer ayers of cells are arranged in irregular masses forming what has been called the zona glomerulosa. The medulla consists of uniting and interlacing cords of polyhedral cells, the cytoplasm of which contains granular matter and a distinct nucleus. When treated with chromic acid or chromium salts the cytoplasm stains a dull brown or yellow color. For this reason they are termed *chromaffin* cells. Similar cells are found in sympathetic ganglia.

The gland receives blood from branches of the renal artery; it discharges its venous blood by way of the adrenal veins into the vena cava on the right side and the renal vein on the left side. The gland cells are excited to activity, the central nerve system through the splanchnics and their continuations, branches from the semi-lunar ganglion.

Destructive pathologic processes of the adrenals produce a profound disturbance of the nutrition first described by Addison and subsequently termed by Trousseau, Addison's disease, which is characterized by extreme muscular weakness and an incapacity for sustained muscle activity; a bronze-like discoloration of the skin and mucous membranes, disturbance of the digestive functions, indicated by indigestion, vomiting and diarrhea; a feeble action of the heart; a small feeble pulse; a low blood-pressure; a subnormal temperature and a feeble respiration. Death ensues from paralysis of the respiratory muscles.

Surgical removal of these bodies from various animals is invariably and in a short time followed by death, preceded by some of the symptoms characteristic of Addison's disease. Their development, however, is more acute. From the fact that animals so promptly die from extirpation of these bodies, and the further fact that the blood of such animals is toxic to those the subjects of recent extirpation, but not to normal animals, the conclusion was drawn that the function of the adrenal bodies was to remove from the blood some toxic material the product of muscle metabolism. Its accumulation after extirpation gives rise to death through auto-intoxication.

The intravenous injection of adrenal extracts is followed in a very short time by a marked rise in blood pressure and if the dose be large enough, by a cessation of the auricular beat, though the ventricular beat continues though with a slower rhythm. If the vagi are cut previous to the injection or if the inhibition is removed by atropin, the rapidity and vigor of both auricles and ventricles are increased. Whether the inhibitory influence is removed or not, there is a marked increase in the blood-pressure, though it is greater in the former than in the latter instance. This is attributed to a direct stimulation and contraction of the muscle-fibers of the arterioles themselves, and not to vaso-motor influences, as it occurs also after division of the cord and destruction of the bulb. The contraction of the arterioles is quite general, as shown by plethysmographic studies of the limbs, spleen, kidney, etc. The arterioles of the lungs and brain do not contract under its influence to the same extent as do the arterioles in other regions of the body, possibly for the reason that they are not so abundantly supplied with vaso-motor nerves. Applied locally to the mucous membranes, the adrenal extract produces contraction of the blood-vessels and pallor.

The extract also diminishes the tonus of the muscle walls of the intestine and other viscera. Injection of the extract into the peritoneal cavity or into the veins causes hyperglycemia and glycosuria which may last for several hours. All these effects follow an injection of an extract of the medulla only.

The *internal secretion* is represented by the alkaloid termed *epinephrin* or *adrenalin*. This alkaloid produces all the effects of the extracts.

The nerve system influences the secretory activity of the adrenals. The major emotional disturbances increase by percentage of adrenalin in the blood which in turn leads to hyperglycemia and glycosuria.

The Function of the Adrenal Gland.—The function of the adrenal gland, at least of the medullary portion, is to furnish an internal secretion which serves apparently to maintain that degree of frequency and force of the heart-beat and the contraction of the arteriole muscle necessary to maintain the normal blood-pressure; to inhibit as occasion requires, the tonus of muscle walls of various viscera; to cause a mobilization of sugar in the blood when this is necessary, and to increase in some unexplained way the tonus and activity of the skeletal musculature.

The Pancreas.—The pancreas though engaged in the production of an external secretion is yet, by reason of the specialized group of cells, the islands of Langerhans, to be regarded as an organ of an internal secretion as well. These islands it is generally believed are engaged in the secretion of an agent which after entering the blood is carried to the muscles where it activates or assists a glycolytic enzyme in promoting the oxidation of sugar; or it may inhibit normally the stimulating action of adrenalin on the liver cells and thus prevent an excessive output of sugar and the development of hyperglycemia. If the entire pancreas is extirpated and the animal survive the operation, a glycosuria is soon established, followed by a series of symptoms resembling those observed in diabetes mellitus as it occurs in man, viz.: thirst, polyuria, loss of energy, decline in body-weight, etc., followed by death in a few weeks. Pathologic processes that involve a large portion of the pancreas likewise give rise to a similar series of phenomena, as ligation of the pancreatic duct, a procedure that leads to a destruction of all portions of the pancreas except the islands of Langerhans and without developing glycosuria has led to the inference that these islands are the agents engaged in the production of the internal secretion.

The Testicles and Ovaries.—The testicles and ovaries are regarded at the present time as glands for the production of an internal secretion, as well as for the production of the characteristic reproductive elements. The removal of the testicles early in life and before the age of puberty leads to imperfect development of the vesiculæ seminales and the prostate gland; in addition to these defects, there is a failure of development of the various and distinctly sexual characters peculiar to man and other animals as well. Sexual desire is wanting and the body frequently remains in the infantile state. Transplantation of the testicles, in cocks and in certain of the smaller mammals that have been castrated, has led to the develop ment of the secondary sexual characters which in no apparent way differed from those of control animals.

The ovaries are also regarded as glands for the production of an internal secretion, as well as for the production of characteristic reproductive elements.

The removal of the ovaries of human beings early in life is an operation that is not often performed and hence it is difficult to state the results that might arise. Their removal in certain animals leads to an atrophy of the uterus, and in addition, to a failure of development of secondary sexual characters. Menstruation does not occur and the body does not reach maturity. The removal of the ovaries in adult life results in a cessation of menstruation, and the appearance of a variety of disorders of a bodily and mental character. Similar phenomena are frequently observed at the menopause, when the ovaries undergo degenerative changes. The administration of extracts of the ovaries—oöphorin tablets—is claimed to relieve some of the symptoms following the removal of the ovaries or occurring during the menopause. The transplantation of an ovary into the wall of the uterus or into the broad ligament after ovariotomy in women has, even after the lapse of two years, reëstablished menstruation and wakened sexual desire.

The Spleen.—Though a ductless gland it can hardly be said that the spleen is a gland of internal secretion inasmuch as no experimental procedure supports such a view. Notwithstanding all the experiments which have been made to determine the functions of the spleen, it can not be said that any very definite results have been obtained. The fact that the spleen can be removed from the body of an animal without appreciably interfering with the normal metabolism would indicate that its function is not very important. The chief changes observed after such a procedure are an enlargement of the lymphatic glands and an increase in the activity of the red marrow of the bones. The presence of large numbers of leukocytes in the splenic pulp and in the blood of the splenic vein suggested the idea that the spleen is engaged in the production of leukocytes, and to this extent contributes to the formation of blood. The presence of disintegrated red blood-corpuscles has suggested the view that the spleen exerts a destructive action on functionally useless red corpuscles. These and other theories as to splenic functions have been offered by different observers, but all are lacking positive confirmation.

Plethysmographic studies show, that the splenic volume increases and decreases in response to the rise and fall of blood pressure. In addition to these rhythmic variations the spleen steadily increases in volume for a period of five hours after digestion, and then steadily declines and returns to its former condition.

THE CENTRAL AND PERIPHERAL ORGANS OF THE NERVE SYSTEM

All the neurons that collectively constitute the nerve system are grouped into more or less completely organized masses termed organs which in accordance with their location may be divided into (1) central organs and (2) peripheral organs.

The Central Organs.—The central organs of the nerve system are the encephalon and the spinal cord, lodged within the cavity of the cranium and the cavity of the spinal column respectively. The general shape of these two portions of the nerve system correspond with that of the cavities in which they are contained. The encephalon is broad and ovoid, the spinal cord is narrow and elongated.

The *encephalon* is subdivided by deep fissures into four distinct, though closely related portions: viz., (1) the cerebrum, the large ovoid mass occupying the entire upper part of the cranial cavity; (2) the cerebellum, the wedge-shaped portion placed beneath the posterior part of the cerebrum and lodged within the cerebellar fossæ; (3) the isthmus of the encephalon, the more or less pyramidal-shaped portion connecting the cerebrum and cerebellum with each other and both with (4) the medulla oblongata.

The *spinal cord* is narrow and cylindric in shape. It occupies the spinal canal as far down as the second or third lumbar vertebra.

The central organs of the nerve system are bilaterally symmetric, consisting of distinct halves united in the median line. The cerebrum is subdivided by a deep fissure, running antero-posteriorly, into two ovoid masses termed *cerebral hemispheres;* the cerebellum is also partially subdivided into hemispheres; the isthmus likewise presents in the median line a partial division into halves; the medulla oblongata and spinal cord are subdivided by an anterior or ventral and a posterior or dorsal fissure into halves, a right and a left.

The Peripheral Organs.—The **peripheral organs of the nerve system** in anatomic and physiologic relation with the central organs, are the encephalic and the spinal nerves.

The *encephalic nerves,* twelve in number on each side of the median line, are in anatomic relation with the base of the encephalon, and because of the fact that they pass through foramina in the walls of the cranium they are usually termed cranial nerves.

The *spinal nerves,* thirty-one in number on each side, are in anatomic relation with the spinal cord, and because of the fact that they pass through foramina in the walls of the spinal column they are termed spinal nerves. As both cranial and spinal nerves are ultimately distributed to the structures of the body—*i.e.,* the general periphery—they collectively constitute the *peripheral organs of the nerve system.*

The spinal nerves consist of two groups of nerve-fibers, a ventral and a dorsal group. Though closely intermingled in the common trunk of the spinal nerve they are distinctly separated near the spinal cord. Owing to their connection with the ventral and dorsal surfaces of the spinal cord they have been termed respectively the ventral and dorsal roots. Peripherally the ventral root fibers are distributed to skeletal muscles, glands, walls of blood-vessels and walls of various viscera: the dorsal root fibers are distributed to skin, mucous membranes, muscles, joints, etc.

The relation of the ventral and dorsal roots of the spinal nerves to the spinal cord, the classification of their contained nerve fibers and their various functions have been considered in a previous section (see pages 42, 44).

The encephalic nerves also consist of afferent and efferent nerve fibers which pass for the most part to their destinations as separate and independent nerves. Their relation to the encephalon and the phenomena that follow their stimulation and division and the functions attributed to them will be fully considered in a subsequent section.

SPINAL CORD

The spinal cord varies from 10 to 45 cm., in length; is 12 mm. in thickness, weighs 42 grams and extends from the atlas to the second lumbar vertebra, terminating in the *filum terminale.* It is cylindric in shape, and presents an enlargement in the lower cervical and lower dorsal regions, corresponding to the origin of the nerves which are distributed to the upper and lower extremities. The cord is divided into two lateral halves by the anterior and posterior fissures. It is composed of both *white* or *fibrous* and *gray* or *vesicular* matter, the former occupying the exterior of the cord, the latter the interior, where it is arranged in the form of two crescents, one in each lateral half, united by the central mass, the *gray commissure;* the white matter being united in front by the *white commissure.*

Segmentation of the Spinal Cord.—For the elucidation of many problems connected with the physiologic actions of the spinal cord, as well as of the symptoms which follow its pathologic impairment, it will be found helpful to consider the cord as consisting physiologically of a series of segments placed one above the other, the number of segments corresponding to the number of spinal nerves. Each spinal segment would therefore comprise that portion of the cord to which is attached a pair of spinal nerves. The nerve-cells in each segment are in histologic and physiologic relation with definite areas of the body, embracing muscles, blood-vessels, glands, skin, etc.

If the exact distribution of the nerves of any segment were then known, its function could be readily stated. By virtue of this segmentation it becomes possible for each segment to act independently, or in coöperation with other segments, near or remote, with which they are associated by the intrinsic or associative cells and their axons; and the spinal cord itself is enabled to act as a unit.

Structure of the Gray Matter.—The gray matter is arranged in the forms of two crescents, united by a commissural band, forming a figure resembling the letter **H.** Each crescent presents a *ventral* and a *dorsal* horn. The center of the commissure presents a canal which extends from the fourth ventricle downward to the filum terminale. The ventral horn is short and broad and does not extend to the surface. The dorsal horn is narrow and elongated and extends quite to the surface. It is covered and capped by the *substantia gelatinosa.* The gray matter consists primarily of a framework of fine connective tissue, supporting blood-vessels, lymphatics, medullated and non-medullated nerve-fibers, and groups of **nerve-cells.**

Nerve-Cells.—The nerve-cells are arranged in groups, which extend for some distance throughout the cord, forming columns more or less continuous. The first group is situated in the ventral horn, the cells of which are large, multipolar, and connected with the ventral roots of the spinal nerves, and are supposed to be motor in function. The second group is situated in the dorsal horn, the cells of which are spindle-shaped, and from their relation to the posterior roots are supposed to be sensory in function. The third group is situated in the lateral aspect of the gray matter, and is quite separate and distinct, except in the lumbar and cervical enlargements, where it blends with those of the ventral horn. A fourth group is situated at the inner base of the dorsal horn; it begins about the seventh or eighth cervical nerve and extends downward to the second or third lumbar, being most prominent in the dorsal region. This column is known as Clark's vesicular column.

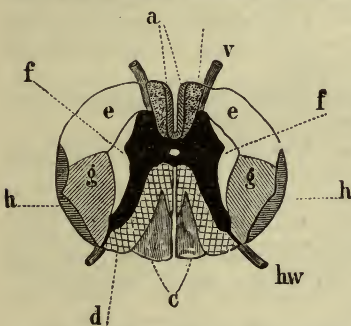

FIG. 15.—SCHEME OF THE CONDUCTING PATH IN THE SPINAL CORD AT THE THIRD DORSAL NERVE.—(*Landois.*)

The black part is the gray matter. v, Ventral, hw, dorsal root. a, Direct, and g,g, crossed, pyramidal tracts. b, Ventral funiculus, ground bundle. c, Goll's column. d, Postero-external or Burdach's column. e,e, and f,f, Mixed lateral paths. h,h, Direct cerebellar tracts.

The nerve cells may be divided into three groups, viz.: intrinsic, receptive and emissive.

The Relation of the Dorsal Roots of the Spinal Nerves to the Intra-Spinal Cells.—The nerve fibers composing the dorsal roots may be divided into two groups, viz.; 1. those distributed peripherally to skin and mucous membrane and 2. those distributed to tendons, joints and muscles. The fibers of the first group receive their stimulation from objects in the external world and have therefore been termed *exteroceptive;* the fibers of the second group receive their stimulation from changes taking place in and around the structures in which they terminate and hence have been termed *proprioceptive.* The centrally directed fibers of the first group, the exteroceptive, on entering the cord became related in part either directly or indirectly through an intercalated neuron, with motor cells in the ventral horn and also in part with afferent or receptive cells at the base of the dorsal horn. The fibers of the second group, the proprioceptive, become related in part to the motor cells of the ventral horn, to the cells composing Clark's vesicular column and in part after ascending the dorsal funiculus to the cells composing the *clavate* and *cuneate* nuclei.

THE FUNCTIONS OF THE GRAY MATTER

The efferent cells of the spinal segments are the immediate sources of the nerve energy that excites activity in skeletal muscles, glands, vascular, and to some extent visceral muscles.

The discharge of their energy many be caused:

1. By variations in the composition of the blood or lymph by which they are surrounded or as the outcome of a reaction between the chemic constituents of the lymph on the one hand and the chemic constituents of the nerve-cell on the other hand. The excitation of the cell thus occasioned is termed *automatic* or *autochthonic excitation.*

2. By the arrival of nerve impulses, coming through afferent nerves from the general periphery, skin, mucous membrane, etc.

3. By the arrival of nerve impulses descending the spinal cord from cells in the cortex of the cerebrum or subordinate regions.

The excitation in the former instances is said to be *reflex* or *peripheral* in origin; in the latter instance *direct* or *cerebral* in origin. In the direct or cerebral excitations the skeletal muscle movements are due to volitional, the gland discharges and vascular and visceral muscle movements to emotional, phases of cerebral activity.

Automatic Excitation.—By this expression is meant a discharge of energy from the spinal nerve-cells occasioned by (*a*) a change in the chemic composition of the blood and lymph by which they are surrounded or probably a reaction between the constituents of the lymph and the constituents of the nerve-cell or (*b*) the developments within the cell of a stimulus, the so-called "inner stimulus," the outcome of metabolic activity.

As illustrations of such activity may be mentioned: (*a*) the contraction of the abductor muscle of the larynx (the posterior crico-arytenoid) whereby the vocal membranes are separated and the glottis kept open under all circumstances except during the emission of vocal sounds; (*b*) the contraction of the dilatator muscle of the iris; (*c*) the contraction of the anal and vesic sphincters; (*d*) the periodic contraction of the respiratory muscles; (*e*) the acceleration of the heart-beat; (*f*) the more or less continuous contraction of the arteriole muscles whereby the blood-pressure is largely maintained. The nerve centers exciting these structures are inferred to be in a condition of continuous automatic activity though capable of modification by nerve impulses reflected to them from more or less distant sources.

Reflex Excitation.—It has already been stated that the nerve-cells in the spinal cord are capable of receiving and transforming afferent nerve impulses, the result of peripheral stimulation, into efferent nerve impulses, which are reflected outward to skeletal muscles, exciting contraction; to glands, provoking secretion; to blood-vessels, changing their caliber; and to organs, inhibiting or augmenting their activity. All such actions taking place through the spinal cord and medulla oblongata independently of sensation or volition are termed reflex actions. The mechanism involved in every reflex action consists of at least the following structures, viz.:

1. A receptive surface; *e.g.*, skin, mucuous membrane, sense organ, etc.
2. An afferent fiber and cell.
3. An emissive cell, from which arises—
4. An efferent nerve, distributed to—
5. A responsive organ, as muscle, gland, blood-vessel, etc.

If a stimulus of sufficient intensity be applied to the receptive surface, there will be developed in the terminals of the afferent nerve a series of nerve impulses which will be transmitted by the afferent nerve to, and received by, the dendrites of the emissive cell in the anterior horn of the gray matter. With the reception of these impulses there will be a disturbance in the equilibrium of the molecules of the cells, a liberation of energy, and a transmission of nerve impulses outward through the efferent nerve to the skeletal muscle, gland-epithelium, vascular or visceral muscle.

In preceding sections many illustrations of reflex actions have been presented in connection with the consideration of the mechanism of mastication; the secretion of saliva; the muscle, glandular and vascular phenomena of gastric and intestinal digestion; the vascular and respiratory movements, the mechanism of micturition, etc.

Special Reflex Movements.—Among the reflexes connected with the more superficial portions of the body there are some which are so frequently either increased or diminished in pathologic conditions of the spinal cord that their study affords valuable indications as to the seat and character of the lesions. They may be divided into:

1. The skin or superficial reflexes.
2. The tendon reflexes.
3. The organ reflexes.

The skin reflexes, characterized by contraction of underlying muscles are induced by stimulation of the afferent nerve-endings of the skin—*e.g*, by pricking, pinching, scratching, etc. The following are the principal skin reflexes:

1. *Plantar reflex*, consisting of contraction of the muscles of the foot, induced by stimulation of the sole of the foot; it takes place through the segments of the cord which give rise to the second and third sacral nerves.

2. *Gluteal reflex*, consisting of contraction of the glutei muscles when the skin over the buttock is stimulated; it takes place through the segments giving origin to the fourth and fifth lumbar nerves.

3. *Cremasteric reflex*, consisting of a contraction of the cremaster muscle and a retraction of the testicle toward the abdominal ring when the skin on the inner side of the thigh is stimulated; it takes place through the segments which give origin to the first and second lumbar nerves.

4. *Abdominal reflex*, consisting of a contraction of the abdominal muscles when the skin upon the side of the abdomen is gently scratched; it takes place through the spinal segments which give origin to the nerves from the eighth to the twelfth thoracic.

5. *Epigastric reflex*, consisting of a slight musclar contraction in the neighborhood of the epigastrium when the skin between the fourth and sixth ribs is stimulated; it takes place through the segments of the cord which gives origin to the nerves from the fourth to the seventh thoracic inclusive.

6. *Scapular reflex*, consisting of a contraction of the scapular muscle when the skin between the scapulæ is stimulated; it takes place through the segments of the cord which gives rise to the nerves from the fifth cervical to the third thoracic inclusive.

The skin or superficial reflexes, though variable, are generally present in health. They are increased or exaggerated when the gray matter of the cord is abnormally excited, as in tetanus, strychnin-poisoning, and disease of the lateral columns.

The so-called "*tendon reflexes*" are characterized by a movement of certain parts of the body due to the contraction of certain muscles and are elicited by a sharp tap on their tendons. The fundamental condition for the production of the tendon reflex is a certain degree of tonus of the muscle, which is a true reflex, maintained by afferent nerve impulses developed in the muscle itself in consequence of its extension and hence compression of the end-organs, the muscle spindles, of the afferent nerves. When the muscle is passively extended, as it must be when the reflex is to be elicited, there is an exaltation of the tonus and an increase in the irritability. To this condition of the muscle due to passive tension, the term myotatic irritability has been given. If the muscle extension be now suddenly increased, as it is when the tendon is sharply tapped, the increased compression of the muscle spindles will develop additional afferent impulses which after transmission to the spinal cord will give rise to contraction of the corresponding muscle. The tendon reflexes are of much value in the diagnosis of certain lesions of the spinal cord.

The following are the principal forms of the tendon reflexes:

1. *The Patellar tendon reflex or knee-jerk.* This phenomenon is characterized by a quick extension of the leg from the knee downward, due to the contraction of the extensor muscles of the thigh, when the ligamentum patellæ is struck between the patella and tibia. This reflex is best observed when the legs are freely hanging over the edge of a table. The patella reflex is generally present in health, being absent in only 2 per cent.; it is greatly exaggerated in lateral sclerosis, in descending degeneration of the cord.; it is absent in locomotor ataxia and in atrophic lesions of the anterior gray cornua.

2. *The tendo-Achilles reflex or ankle-jerk.* This phenomenon is characterized by a flexion of the foot due to a contraction of the gastrocnemius muscle when the tendo-Achillis is struck. To elicit the contraction, the leg should be extended and the dorsum of the foot be pressed toward the leg so as to give to the gastrocnemius a slight degree of extension. If the tendon be now sharply struck a quick flexion of the foot is produced.

3. *Ankle clonus.*—This phenomenon consists of a series of rhythmic contractions of the gastrocnemius muscle, varying in frequency from six to ten per second. To elicit this reflex, pressure is made upon the sole of the foot so as to extend the foot at the ankle suddenly and energetically, thus putting the tendo-Achillis and the gastrocnemius muscle on the stretch. The rhythmic movements thus produced continue so long as the tension within limits is maintained. Ankle clonus is never present in health, but is very marked in lateral sclerosis of the cord.

4. *The Toe reflex.*—This phenomenon is characterized by a flexion of the foot, then of the leg and perhaps of the thigh when the great toe is strongly and suddenly flexed. It is present in those diseases of the spinal cord in which there is a pronounced patellar reflex.

5. *The Wrist and Elbow reflex.*—These phenomena are characterized by an extension movement of the hand and arm when the tendons of the extensor muscles are sharply tapped. These reflexes are especially marked in primary lateral sclerosis of the cord in the upper portion.

The *organ reflexes, e.g.*, the activities of the genito-urinary organs, the stomach, intestines, gall-bladder, etc., which are induced by peripheral stimulation have been considered in connection with the physiologic action of these organs. The genito-urinary center is located in the lumbar region of the spinal cord. In diseased conditions of this region the genito-urinary reflexes are sometimes increased, at other times decreased or even abolished.

Reflex Irritability.—The general irritability or quickness of response of the mechanism involved in a reflex act is approximately represented by the length of time that elapses between the application of a minimal stimulus and the appearance of the muscle response. The total reflex time is a variable factor in different individuals and depends very largely on the degree of irritability of the intra-spinal mechanism. If this is *increased* the entire duration of the reflex act is shorter; if it is *decreased* the duration is lengthened—*e.g.*,

The irritability of the cord may be—

1. *Increased*, by disease of the lateral columns, by the administration of strychnin and in frogs, by a separation of cord from the brain, the latter apparently exerting an inhibitor influence over the former and depressing its reflex activity.

2. *Decreased*, by destructive lesion of the cord—*e.g.*, locomotor ataxia, atrophy of the anterior cornua—the administration of various drugs, and in the frog, by irritation of certain regions of the brain. When the cerebrum alone is removed and the optic lobes are stimulated, the time elapsing between the application of an irritant to a sensor surface and the resulting movement will be considerably prolonged, the optic lobes (Setschenow's center) apparently generating impulses which, descending the cord, retard its reflex movement.

Special Nerve Centers in Spinal Cord.—Throughout the spinal cord there are a number of spinal nerve centers, capable of being excited reflexly and of producing complex coördinated movements. Though for the most part independent in action, they are subject to the controlling influences of the medulla and brain.

1. *Ciliospinal* center, situated in the cord between the lower cervical and the third dorsal vertebra. It is connected with the dilatation of the pupil through fibers which emerge in this region and enter the cervical sympathetic. Stimulation of the cord in this locality causes dilatation of the pupil on the same side; destruction of the cord is followed by contraction of the pupil.

2. *Genitospinal* center, situated in the lower part of the cord. This is a complex center, and comprises a series of subordinate centers for the control of the muscular movements involved in the acts of defecation, micturition, and ejaculation of semen, and of the movements of the uterus during parturition, etc.

3. *Vaso-motor* centers, giving origin to both vaso-constrictor and vaso-dilatator fibers, which are distributed throughout the cord between the first thoracic and third lumbar nerves.

Though acting reflexly, they are under the dominating influence of the center in the medulla.

4. *Sweat* centers are also present in various parts of the cord.

Direct or Cerebral Excitation.—The activity of the emissive cells of the spinal cord segments, due to the arrival of nerve impulses descending the spinal cord from the cerebrum, in consequence of psychic states of a volitional or of an affective or emotional character, will be considered in a subsequent paragraph entitled "encephalo-spinal conduction."

The Structure of the White Matter.—The white matter of each half of the spinal cord is anatomically divided by the ventral and dorsal roots into a ventral, a lateral and a dorsal funiculus or column. The white matter of each funiculus has been differentiated into a number of specialized tracts which have different origins, destinations and functions. They are divided into: (1) intersegmental, (2) ascending, and (3) descending.

1. *The Intersegmental Tracts.*—The intersegmental tracts comprise the fibers heretofore spoken of as ground bundles, fundamental bundles, etc., bundles of fibers which occupy those regions termed ventral, lateral and dorsal root zones. In as much as they are limited to the spinal cord they are termed *fasciculi proprii* of which there may be distinguished a ventral, a lateral and a dorsal fasciculus. These fibers surround and for the most part lie close to the gray matter throughout its entire extent. These fasciculi consist of fibers of variable length which have their origin in the intrinsic nerve-cells of the gray matter. From their origin the nerve processes pass outward into the white matter on the same and the opposite sides, after which they divide into two branches an ascending and a descending. After a variable distance these branches re-enter the gray matter and through their terminal branches come into relation with other intrinsic nerve-cells. By this means the segments of the spinal cord situated at different levels are united anatomically and associated for the performance presumably of complex reflex activities.

The Ascending Tracts or Fasciculi.—The ascending tracts are found for the most part in the dorsal and lateral funiculi, though a few are found in the ventral funiculus.

The ascending tracts present in the *dorsal funiculus* proceeding from behind forward may be divided into two main groups, viz.: the dorso-internal and the dorso-external.

1. *The Dorso-internal Tract or Fasciculus of Goll.*—This tract lies close to the dorso-median fissure and consists of nerve-fibers which are the continuations of the dorsal roots of the sacral, lumbar and lower thoracic nerves of the same side. After entering the cord they pass upward as far

as the lower portion of the medulla oblongata where their terminal branches arborize around the cells of a nucleus known as the *clavate* or *gracile* nucleus.

2. *The Dorso-external Tract or Fasciculus of Burdach.*—This tract lies just within the dorsal horn and is separated from the dorso-internal tract by a septum of connective tissue most marked above the eleventh thoracic segment. The fibers composing this tract are the continuations of the dorsal roots of the upper thoracic and cervical nerves. After entering, they cross the cord obliquely and pass upward as far as the lower border of the medulla oblongata where their terminal branches arborize around the cells of a nucleus known as the *cuneate* nucleus. Transverse division of the fibers of these tracts is followed by a degeneration upward as far as the cuneate and clavate nuclei, indicating that their trophic center is situated at a lower level.

The ascending tracts present in the *lateral funiculus* are six in number of which the more important are as follows:

1. *The Dorsal Spino-cerebellar Tract, or Tract of Flechsig.*—This tract or fasciculus lies on the dorsal aspect of the lateral funiculus. It slightly increases in size from the level of the second lumbar nerve up to the medulla oblongata. It is composed of nerve-fibers that have their origin in the nerve-cells composing the vesicular column of Clarke on the same side. From their origin the fibers pass obliquely outward to the surface, then turn upward and finally by way of the inferior peduncle enter and terminate as the name implies in the cerebellum. A decussation of the fibers, it is stated, takes place in the superior vermiform process. When transversely divided the peripheral portion of the fibers undergoes degeneration.

2. *The Lateral Spino-cerebellar Tract, or Tract of Gower.*—This tract lies on the ventral aspect of the lateral funiculus. It is composed of fibers which also have their origin in nerve-cells of Clarke's vesicular column on the same side in the lower portion of the cord. From this origin the fibers pass outward to the surface and then pass upward as far as the pons Varolii where for the most part they turn backward and enter the cerebellum by way of the superior peduncle. When transversely divided the peripheral portion of the fibers undergoes degeneration.

3. *The Lateral Spino-thalamic Tract.*—This tract lies just internal to the lateral spino-cerebellar tract and has frequently been confounded with it. It consists of fibers that have their origin in nerve-cells in the dorsal horns of the opposite side.

4. *The Ventral Spino-thalamic Tract.*—This tract is located in the ventral fasciculus proprius just in front of the ventral horn of the gray matter.

The fibers composing this tract likewise have their origin in the nerve-cells in the dorsal horn of the opposite side.

From their origin the fibers of both these tracts cross to the opposite side of the cord and pass upward in the regions just stated to terminate around the cells of the lateral and ventral nuclei respectively of the thalamus. These two spino-thalamic tracts are continued by third neurons, which, arising in the cells of the thalamus, pass upward to the cells of the post-central convolutions of the cortex of the cerebrum and are known as the *thalamo-cortical tracts.*

The Descending Tracts or Fasciculi.—The descending tracts, found in the lateral and ventral funiculi, are four in number as follows:

1. *The Cortico-spinal or Pyramidal Tract.*—The fibers composing this tract are located for the most part, as will be fully stated later, in the central portion of the cortex of the cerebral hemispheres in the neighborhood of the central or Rolandic fissure. The axons of these cells from each hemisphere descend through the corona radiata to and through the internal capsule, along the inferior surface of the crura cerebri, behind the pons to the medulla, of which they constitute the anterior pyramids. At this point the pyramidal tract of each side divides into two portions, viz.:

1. A large portion, containing from 85 to 90 per cent. of the fibers, which decussates at the lower border of the medulla and passes downward in the posterior part of the lateral column of the opposite side, constituting the *crossed pyramidal tract;* as it descends it gradually diminishes in size as its fibers or their collaterals enter the gray matter of each successive segment.

2. A small portion, containing from 15 to 10 per cent. of the fibers, which does not decussate at the medulla but passes downward on the inner side of the anterior column of the same side, constituting the *direct pyramidal tract* or column of Türck. This tract can be traced down, as a rule, only as far as the mid-dorsal region. As it descends it becomes smaller as its fibers cross the anterior commissure to enter the gray matter of the opposite side. Thus all the fibers of the pyramidal tract from each cerebral hemisphere eventually are brought into relation with the cells of the gray matter of the opposite side of the cord.

In addition to the tracts mentioned and found in the three funiculi, other tracts are present but their anatomic relations and physiologic functions are to a considerable extent obscure.

THE FUNCTIONS OF THE WHITE MATTER

The function of the white matter in general is the conduction of nerve impulses up and down the spinal cord. The general function of the white matter may be regarded from at least three points of view, viz.: (1) Intersegmental conduction mediated by the fibers composing the fasciculi proprii; (2) ascending or spino-encephalic conduction mediated by the spino-encephalic tracts or fasciculi; (3) Descending or encephalo-spinal conduction mediated by the encephalo-spinal tracts or fasciculi.

Intersegmental Conduction.—The spinal cord consists of a series of physiologic segments each of which has a special function and is associated through its related spinal nerve with a definite segment of the body. For the harmonious coöperation and coördination of all the spinal segments it is essential that they should be united by commissural or associative fibers. This is accomplished by the fibers constituting the fasciculi proprii. The cord thus becomes capable of complex and purposive reflex actions.

Ascending or Spino-encephalic Conduction.—The conduction of nerve impulses upward necessitates the existence of special tracts which have been alluded to in foregoing paragraphs.

The *exteroceptive fibers* of the dorsal roots which enter the cord become related in part with nerve cells at the base of the dorsal horn. From these cells axons arise which cross the median plane and ascend the cord in the lateral and ventral spino-thalamic tracts. These tracts are continued by new axons emerging from the thalamic cells and ascending to the cerebral cortex. The nerve impulses, brought to the surface by the exteroceptic fibers and which ascend the lateral spino-thalamic tract evoke sensations of *pain* and *temperature;* the impulses which ascend the ventral spino-thalamic tract evoke sensations of *touch* and *pressure*.

The *proprioceptive fibers* which enter the cord become related in part with the cells of Clarke's column on the same side. From the cells axons pass outward by the same side and ascend the dorsal and lateral spinocerebellar tracts—of which they constitute the major portion—as the cerebellum is an organ for the coördination of muscle.

Descending or Encephalo-spinal Conduction.—The conduction of nerve impulses from above downward necessitates the existence of tracts of fibers which extend from the cerebrum to various levels of the medulla and spinal cord.

The Cortico-spinal or Pyramidal Tract.—This tract as previously stated associates the motor area of the cortex with efferent nerve cells in the ventral gray matter of the aqueduct of Sylvius, the pons, the medulla and spinal cord, from these cells the tract is continued to the muscle by the fibers constituting the motor cranial and spinal nerves all of which are distributed to skeletal muscles. Experimental investigations and observations of pathologic processes indicate that the fibers of this tract are efferent pathways for the transmission of motor or volitional nerve impulses from the cortex to the spinal segment, a cross section of the ventral and lateral funiculi on one side of the spinal cord in any part of its extent is invariably followed by a loss of activity or paralysis of the muscles below the section,

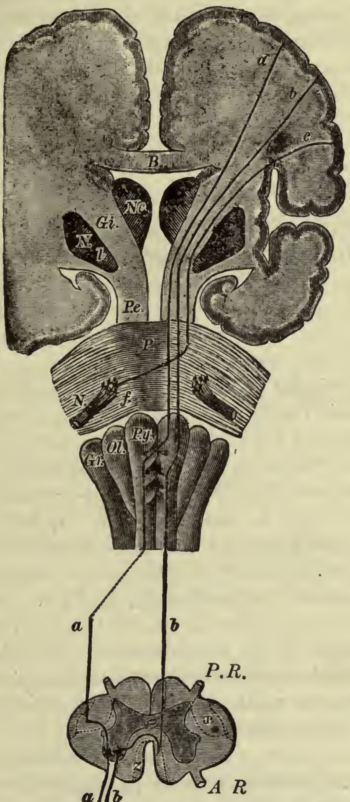

FIG. 16.—COURSE OF THE FIBERS FOR VOLUNTARY MOVEMENT.—(*Landois*.

while electric stimulation of the peripheral end of the isolated crossed pyramidal tract is followed by marked characteristic movements of the muscles. Similar results follow division of the pyramidal tract in any part of its course from the cerebral cortex downward. Electric stimulation of the cortical cells which give origin to the pyramidal tract is also followed by contraction of the muscles of the opposite side, while their destruction is attended by paralysis of the same muscles. As the nutrition of the fibers is governed by the cells, it follows that when the axon is separated from its cell-body it degenerates. It has been found that a lesion of the pyramidal tract in any part of its course is followed by descending degeneration, which is taken in evidence that it conducts nerve impulses from above downward. Thus experimental investigation and pathologic observation are in accord in the view that physiologically these nerve-fibers are the pathways for the transmission of motor or volitional impulses from the encephalon to the spinal cord.

THE MEDULLA OBLONGATA

The medulla oblongata is the expanded portion of the upper part of the spinal cord. It is pyramidal in form and measures 38 mm. in length, 20 mm. in breadth, 12 mm. in thickness, and is divided into two lateral halves by the anterior and posterior median fissures, which are continuous with those of the cord. Each half is again subdivided by minor grooves into three funiculi—viz., *ventral*, *lateral* and *dorsal*.

1. The *ventral funiculus* is composed partly of fibers continuous with those of the ventral funiculus of the spinal cord, but mainly of fibers derived from the lateral tract of the opposite side by *decussation*.—The united fibers can be traced upward through the pons Varolii and crura cerebri, to the corpus striatum and cerebrum where they originate.

2. The *lateral funiculus* is continuous with the lateral fasciculi of the cord; its fibers in passing upward take three directions—viz., an external bundle joins the restiform body, and passes into the cerebellum; an internal bundle decussates at the median line and joins the opposite ventral funiculus; a middle bundle ascends beneath the olivary body, behind the pons, to the cerebrum, as the *fasciculus teres*. The *olivary body* of each side is an oval mass, situated between the ventral funiculus and restiform body; it is composed of white matter externally and gray matter internally, forming the *corpus dentatum*.

3. The *dorsal funiculus* is a narrow white cord bordering the posterior median fissure; it is continued upward, in connection with the *fasiculus teres*, to the cerebrum.

The *restiform body*, continuous with the dorsal funiculus of the cord, also receives fibers from the lateral column. As the restiform bodies pass upward they diverge and form a space (the fourth ventricle), the floor of which is formed by gray matter, and then turn backward and enter the cerebellum.

THE PONS VAROLII

The pons Varolii is united with the cerebrum above, the cerebellum behind, and the medulla oblongata below. It consists of transverse and longitudinal fibers, amidst which are irregularly scattered collections of gray or vesicular nervous matter.

The *transverse fibers* unite the two lateral halves of the cerebellum.

The *longitudinal fibers* are continuous—

1. With the ventral funiculi of the medulla oblongata, which, interlacing with the deep layers of the transverse fibers, ascend to the crura cerebri, forming their superficial or fasciculated portions.

2. With fibers derived from the olivary fasciculus, some of which pass to the tubercula quadrigemina, while others, uniting with fibers from the lateral and posterior funiculi of the medulla, ascend in the deep or posterior portions of the crura cerebri.

The Gray Matter of the Medulla and Pons Varolii.—The gray matter of both the medulla oblongata and pons is continuous with that of the spinal cord. It is arranged however with much less regularity. It forms a thin layer just beneath the floor of the fourth ventricle. Special groups of nervercells are found in it, some of which give origin to different cranial nerves.

Functions of the Medulla and Pons.—By virtue of the presence of nerve-cells and definite tracts of nerve fibers the structures may be regarded as consisting:

1. Of nerve centers, each of which has a special function, and

2. Of conducting paths, by which these centers are brought into relation not only with one another but with the cerebrum, the cerebellum and the spinal cord.

The efferent or emissive nerve cells are excited to action by the same factors that excite to action the motor or efferent cells of the spinal cord (see page 173), viz.: (*a*) by local causes, (*b*) by the arrival of nerve impulses reflected from the skin and (*c*) by nerve impulses descending from the cerebrum or subordinate regions.

The groups of nerve cells may be regarded therefore as centers for automatic, reflex and volitional activities. Some of these centers are as follows:

1. The *cardiac centers*, which exert (1) an *accelerator* action over the heart's pulsations through nerve fibers emerging from the spinal cord in the roots of the first and second dorsal nerves and reaching the heart through the sympathetic nerve; (2) an *inhibitor* or *retarding* action on the

rate of the heart-beat through efferent fibers in the trunk of the pneumogastric or vagus nerve. (See pages 111 and 112.)

2. A *vaso-motor center*, which regulates the caliber of the blood-vessels throughout the body in accordance with the needs of the organs and tissues for blood, through nerve-fibers passing by way of the spinal nerves to the walls of the blood vessels. (See page 121.)

3. A *respiratory center*, which coördinates the muscles concerned in the production of the respiratory movements. (See page 133.)

4. A *mastication center*, which excites to activity and coördinates the muscles of mastication.

5. A *deglutition center*, which excites and coördinates the muscles concerned in the transference of the food from the mouth to the stomach.

6. An *articulation center*, which coördinates the muscles necessary to the production of articulate speech.

7. A *diabetic center*, stimulation of which gives rise to glycosuria.

8. A *salivary center*, stimulation of which excites the discharge of saliva.

The Medulla and Pons as Conductors.—The anterior funiculi of the medulla and their continuations through the more ventral portions of the pons, being portions of the general pyramidal tract, serve to conduct volitional efferent nerve impulses from higher portions of the brain to the spinal cord. Division of these pathways is at once followed by a loss of volitional control of the muscles below the section.

The dorsal or tegmental portion, containing the fillet, serves to transmit afferent nerve impulses from the spinal cord to higher portions of the brain. Transverse division of one-half of the dorsal portion of the pons is followed by complete anesthesia of the opposite half of the body without any impairment of motion.

The restiform bodies constitute a pathway between the spinal cord and the cerebellum. The transverse fibers of the pons associate opposite but corresponding portions of the cerebellar hemispheres.

THE CRURA CEREBRI

The crura cerebri are largely composed of the longitudinal fibers of the pons (anterior funiculi, fasciculi teretes); after emerging from the pons they increase in size, and become separated into two portions by a layer of dark-gray matter, the *locus niger.*

The *superficial* portion, the *crusta*, composed in part of the anterior pyramids, constitutes the *motor tract*, which terminates, to some extent, in the *corpus striatum*, but for the most part, in the cerebrum; the *deep portion*, made up of the fasciculi teretes and posterior funiculi and accessory fibers from the cerebellum, constitutes the *sensor tract* (the *tegmentum*) which terminates in the *optic thalamus* and cerebrum.

The *gray matter* is situated beneath the aqueduct of Sylvius and contains groups of nerve-cells which give origin to the nerve-fibers composing the third or oculo-motor nerve.

Function.—The crura are conductors of motor and sensor impulses; the gray matter assists in the coördination of the complicated movements of the eyeball and iris, through the motor oculi communis nerve. It also assists in the harmonization of the general muscular movements, as section of one crus gives rise to peculiar movements of rotation and somersaults forward and backward.

THE CORPORA QUADRIGEMINA

The corpora quadrigemina are four small grayish eminences situated beneath the posterior border of the corpus callosum and behind the third ventricle. They rest upon the lamina quadrigemina, which forms the roof of the aqueduct of Sylvius. The superior pair are the larger and are known as the *superior quadrigeminal bodies*, the *superior colliculi* or the *pregemina;* the inferior pair are the smaller and are known as the *inferior quadrigeminal bodies*, the *inferior colliculi*, or the *post-gemina.*

External and somewhat inferior to the corpora quadrigemina are two small collections of gray matter the more external of which has been termed the *external geniculate body* or the *pregeniculum*, the more internal of which has been termed the *internal geniculate body* or the *post-geniculum.*

Though these bodies are closely associated anatomically, they differ in origin, in their relations, and in their functions.

The corpora quadrigemina show on microscopic examination that they are composed of nerve-cells and nerve-fibers, both of which are so intricately arranged that it is difficult to trace their relation one to another and to adjoining structures. Some of the cells of the superior quadrigeminal body give origin to axons which pass downward and forward and terminate in brush-like expansions around the nuclei of origin of the oculo-motor, trochlear, and abducent nuclei; other cells are surrounded by the terminal branches of some of the fibers of the optic tract, though it is not probable that they are true visual fibers. Still other cells receive the terminal branches of axons the cells of origin of which are located in the occipital cortex of the cerebrum and which reach the superior quadrigeminal body by way of the optic radiation and internal capsule.

The cells of the post-geminum give origin to axons which pass upward, forward, and outward, enter the internal capsule, and pass by way of the auditory tract to the cortex of the temporo-sphenoidal region of the cerebrum. Many of the fibers of the lateral fillet, a portion of the auditory tract, terminate in brush-like expansions around these same cells. There is thus established a connected pathway between the cochlea and the temporo-sphenoidal cortex.

The external geniculate body is a terminal station for a portion of the fine visual fibers coming from the retina. From the cells of this body new axons arise which course forward and upward, enter the internal capsule and pass by way of the optic radiation to the cortex of the occipital region of the cerebrum.

Functions.—From the anatomic relation of the superior quadrigeminal body (the pre-geminum) to the optic tract, the inference can be drawn that it is in some way essential to the performance of various reflex ocular movements and perhaps to the variations in size of the pupil. Experimental investigations and pathologic changes support the inference.

Irritation of the pre-geminum in monkeys on one side is followed by diminution of the pupils first on the opposite side and then almost immediately on the same side. The eyes at the same time are also widely opened and the eyeballs turned upward and to the opposite side. If the irritation be continued, motor reactions are exhibited in various parts of the body. Destruction of the pre-geminum in both monkeys and rabbits is followed by blindness, dilatation and immobility of the pupils, with marked disturbance of equilibrium and locomotion (Ferrier).

From the anatomic relation of the inferior quadrigeminal body (the post-geminum) to the lateral fillet, the basal tract for hearing, the inference may be drawn that it is in some way connected with the auditory process.

Stimulation of the post-geminum gives rise to cries and various forms of vocalization. Pathologic states of this body are also attended by impairment of hearing and disorders of the equilibrium.

From the foregoing facts it is probable that the corpora quadrigemina are associated with station and locomotion. Ferrier assumes that in these bodies "sensory impressions, retinal and others, are coördinated with adaptive motor reactions such as are involved in equilibration and locomotion."

CORPORA STRIATA AND OPTIC THALAMI

The corpora striata are two large ovoid collections of gray matter, situated at the base of the cerebrum, the larger portions of which are embedded in the white matter, the smaller portions projecting into the anterior part of the lateral ventricle. Each striated body is divided by a narrow band of white matter into two portions—viz.:

1. The *caudate nucleus*, the intraventricular portion, which is conic in shape, having its apex directed backward, as a narrow, tail-like process.

2. The *lenticular nucleus*, embedded in the white matter, and for the most part external to the ventricle. On the outer side of the lenticular nucleus is found a narrow band of white matter, the *external capsule;* and between it and the convolutions of the island of Reil, a thin band of gray matter, the *claustrum.*

The corpora striata are grayish in color, and when divided, present transverse striations, from the intermingling of white fibers and gray cells.

Functions.—The functions of the cells composing the caudate and lenticular nuclei are very obscure. It is stated by some experimenters that localized stimulation both of a physiologic and pathologic character is followed by a persistent rise of temperature varying from 1° to 2.6°C.

The optic thalami are two oblong masses situated in the ventricles posterior to the corpora striata, and resting upon the posterior portion of the crura cerebri. The internal surface, projecting into the lateral ventricles, is white, but the interior is grayish, from a commingling of both white fibers and gray cells. Separating the lenticular nucleus from the caudate nucleus and the optic thalamus is a band of white tissue, the *internal* capsule.

Functions.—From the anatomic relation of the optic thalami to the general and special sense nerve-tracts, on the one hand, and to the cerebral cortex, on the other hand, it is assumed that they are connected with the production of sensations both general and special, and act as intermediaries between the peripheral sense-organs and the cortex.

It is probable that in the thalamus visual, tactile, and labyrinthine impressions are received, coördinated, and reflected outward, with the result of producing various adaptive motor reactions connected with station and equilibrium. The thalamus is believed by some investigators to act also as an intermediary between emotional states and their expression in the muscles of the face, this power being lost in certain pathologic conditions. The power of regulating the temperature of the body has been also assigned to the thalamus, as destruction of its anterior extremity is usually followed by a rise in temperature.

The Internal Capsule.—The lenticular nucleus is enclosed on all sides by ascending and descending nerve-fibers. From the manner in which they surround and enclose the nucleus they have collectively been called the *lenticular capsule*. If a horizontal section of the cerebrum be made at a certain level so as to cut across the capsule and the enclosed nucleus an appearance similar to that shown in Fig. 17, will be presented. That portion of the capsule that lies between the caudate nucleus and the optic thalamus internally, and the lenticular nucleus externally is known as the internal portion of the lenticular capsule, or in its abbreviated form as the

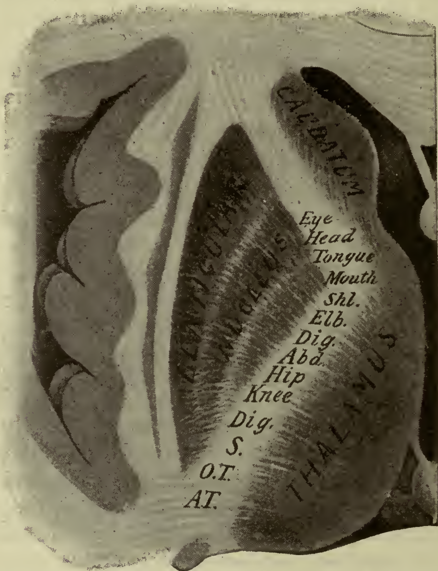

FIG. 17.—HORIZONTAL SECTION OF THE INTERNAL CAPSULE SHOWING THE POSITION AND RELATION OF THE MOTOR TRACTS FOR THE EYE, HEAD, TONGUE, MOUTH, SHOULDER (Shl.), ELBOW (Elb.), DIGITS OF HAND (Dig.), ABDOMEN (Aeb.), HIP, KNEE (Kn.), DIGITS OF FOOT (Dig.). S. Sensor tract. O.T. Optic tract. A.T. Auditory tract.

internal capsule, while that portion between the external convex border of the lenticular nucleus and the claustrum is known as the external portion of the lenticular capsule or in its abbreviated form as the *external capsule*. At a given level the internal capsule may be said to consist of two segments or limbs, an *anterior*, situated between the caudate nucleus and the anterior extremity of the lenticular nucleus, and a *posterior*, situated between the optic thalamus and the posterior extremity of the lenticular nucleus. The two segments unite at an obtuse angle, termed the knee, which is directed toward the median line. The appearance which is presented at different levels varies however considerably.

Functions.—The internal capsule has been shown by the results both of experiment and of pathologic processes to be, first, a pathway for the transmission of nerve impulses from the cerebral cortex to the pons, medulla, and spinal cord, which give rise to contraction of the muscles of the opposite side of the body; and, second, a pathway for the transmission of nerve impulses coming from skin, mucous membrane, muscles, and special sense organs to the cortex, where they give rise to sensations general and special. It is, therefore, the common motor and sensor pathway. For the reason that it transmits both motor and sensor impulses, and for the further reason that it is frequently the seat of pathologic lesions which are followed by either a loss of motion or sensation or both, the internal capsule is one of the most interesting parts of the central nerve system. The *motor* tract is confined to the posterior one-third of the anterior segment and the anterior two-thirds of the posterior segment. The *sensor* tract is confined to the posterior one-third of the posterior segment, the extreme end of which also contains the optic and auditory tracts.

The region of the anterior segment in front of the motor tract contains the fibers of the fronto-cerebellar tract, the function of which is unknown.

The motor region contains fibers which descend from the cerebral cortex to nerve centers situated in the gray matter beneath the aqueduct of Sylvius, in the gray matter beneath the floor of the fourth ventricle, and in the anterior horns of the gray matter of the spinal cord, and in turn are connected by the cranial and spinal nerves with the muscles of the eye, head, face, trunk, and limbs. The positions occupied by these different tracts are shown in Fig. 17.

From the fact that the internal capsule contains efferent or motor tracts, and afferent or sensor tracts, it is evident that a destructive lesion of the motor tract would be followed by a loss of motion; and of the sensor tract, by a loss of sensation, on the opposite side of the body.

THE CEREBRUM

The cerebrum is the largest portion of the encephalon, constituting about 85 per cent. of its total weight. In shape it is ovate, convex on its outer surface, narrow in front and broad behind. It is divided by a deep longitudinal cleft or fissure into halves, known as the cerebral hemispheres. The hemispheres are completely separated anteriorly and posteriorly by this fissure, but in their middle portions are united by a broad white band

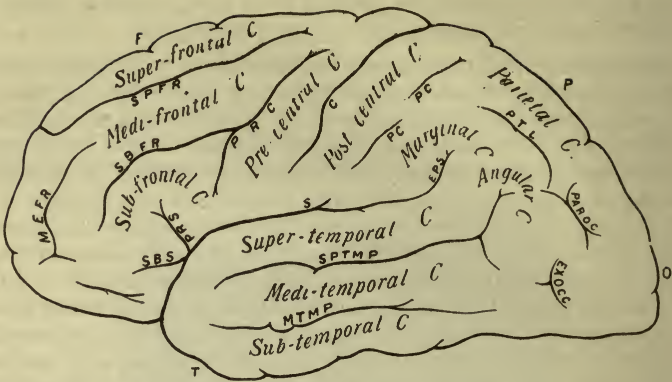

FIG. 18.—DIAGRAM SHOWING FISSURES AND CONVOLUTIONS ON THE LATERAL ASPECT OF THE LEFT HEMI-CEREBRUM.

F, Frontal. *P*, Parietal. *T*, Temporal and *O*, Occipital lobes. *S*. Fissures of. Sylvius. *EPS*. Epi-sylvian. *PRS*. Pre-sylvian. *SBS*. Sub-sylvian fissures. *C*. Central fissure or fissure of Rolando. *PRC*. Precentral fissure. *SPFR*. Superfrontal fissure. *MEFR*. Media-frontal fissure. *SBFR*. Sub-frontal fissure. *PCPC*. Post-central fissure. *PTL*. Parietal fissure. *PAROC*. Par-occipital. *EXOCC*. Ex-occipital fissures. *SPTMP*. Super-temporal fissure. *MTMP*. Medi-temporal fissure.

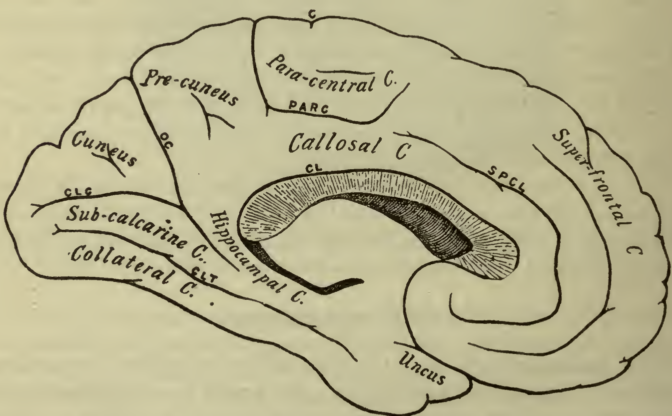

FIG. 19.—DIAGRAM SHOWING FISSURES AND CONVOLUTIONS ON THE MESAL ASPECT OF THE LEFT HEMI-CEREBRUM.

c. Upper extremity of the central fissure. *PARC*. Para-central fissure. *SPCL*. Super-callosal fissure. *CL*. Callosal fissure. *OC*. Occipital fissure. *CLC*. Calcarine fissure. *CLT*. Collateral fissure.

of nerve-fibers, the corpus callosum. Each hemisphere or hemi-cerebrum is convex on its outer aspect, and corresponds in a general way with each side of the cavity of the skull; the inner or mesial surface is flat and forms the lateral boundary of the longitudinal fissure.

The surface of each hemi-cerebrum presents a series of alternate indentations and elevations, known respectively as fissures or sulci, and convolutions or gyri. A knowledge of the situation and extent of the principal fissures and convolutions, as well as of their relation one to another, is essential to a clear understanding of many physiologic processes, clinical phenomena, and surgical procedures. A study of the accompanying Figs. 18, 19, diagrams, with the aid of the accompanying legends, will show the location and relations of the more important of these fissures and convolutions.

Structure.—The *gray matter* of the cerebrum, about 3 mm. thick, is composed of five layers of nerve-cells:

1. A superficial layer, containing a few small multipolar ganglion cells.
2. Small ganglion cells, pyramidal in shape.
3. A layer of large pyramidal ganglion cells with processes running off superiorly and laterally.
4. The glandular formation containing nerve-cells.
5. Spindle-shaped and branching nerve-cells of a moderate size.

The *white matter* consists of medullated nerve-fibers which though intricately arranged may be divided into three systems, viz.: the commissural, the association and the projection.

The *commissural* fibers unite corresponding areas of the cortex of each side.

The *association* fibers unite neighboring as well as distant parts of the same hemisphere, and may, therefore, be divided into long and short fibers.

The *projection* fibers unite certain areas of the cerebral cortex with the basal ganglia, the pons, the medulla oblongata, and the spinal cord. They are divided into: (1) afferent fibers which have their origin in the lower nerve centers at different levels and thence pass to the cortex; and (2) efferent fibers which have their origin in the cortex and thence pass to the lower nerve centers, terminating at different levels.

The *afferent fibers*, the so-called sensor tract, which transmit nerve impulses coming from the general periphery and sense-organs, pass through the tegmentum as the mesial and lateral fillets, and thence to the cortex directly by way of the internal capsule, or indirectly through the intermediation of the thalamic and subthalamic nuclei. The distribution of these fibers to the various areas of the cortex will be stated in following paragraphs.

The *efferent fibers* of the so-called motor tract, which transmit motor or volitional nerve impulses from the cortex to the pons, medulla, and spinal cord, emerge from the layer of pyramidal cells of the gray matter of the anterior or the pre-central convolution, the para-central lobule, and immediately adjacent areas. From this origin the axons descend through the white matter of the corona radiata, converging toward the internal capsule, into and through which they pass, occupying the anterior two-thirds of the posterior limb or segment. Beyond the capsule they continue to descend, occupying the middle three-fifths of the pes or crusta of the crus cerebri, the ventral portion of the pons, and eventually the anterior pyramid of the medulla oblongata. At this point the tract divides into two portions, viz.:

1. A large portion, containing from 85 to 90 per cent. of the fibers, which decussates at the lower border of the medulla and passes down the lateral funiculus of the cord, constituting the *crossed pyramidal tract.*

2. A small portion, containing from 15 to 10 per cent. of the fibers, which does not decussate at the medulla, but passes down the inner side of the anterior funiculus of the same side, constituting the *direct pyramidal tract* or column of Türck.

After passing through the internal capsule, and as it descends through the crus, pons, and medulla, the pyramidal tract gives off a number of fibers which cross the median line and arborize around the nerve-cells of the gray matter beneath the aqueduct of Sylvius (the nuclei of origin of the third and fourth cranial nerves), and around the nerve-cells in the gray matter beneath the floor of the fourth ventricle (the nuclei of origin of the remainder of the motor cranial nerves). The remaining fibers go to form the crossed and direct pyramidal tracts and arborize around the cells in the anterior horn of the gray matter of the opposite side of the cord at successive levels. By this means the cortex is brought into anatomic and physiologic relation with the general musculature of the various cranial and spinal motor nerves.

Functions.—The functions of the cerebrum comprehend, in man at least, all that pertains to sensation, cognition, feeling, and volition. All subjective experiences, which in their totality constitute mind, are dependent on and associated with the anatomic integrity and the physiologic activity of the cerebrum and its related sense-organs, the eye, ear, nose, tongue and skin.

From an examination of the anatomic development of the brain in different classes of animals, in different men and races of men, and from a study of the pathologic lesions and the results of experimental lesions of the brain, evidence has been obtained which reveals in a striking manner the intimate connection of the cerebrum and all phases of mental activity.

1. *Comparative anatomy* shows that there is a general connection between the size of the brain, its texture, the depth and number of convolutions, and the exhibition of mental power. Throughout the entire animal series, the increase in intelligence goes hand in hand with an increase in the development of the brain. In man there is an enormous increase in size over that of the highest animals, the anthropoids. The most cultivated races of men have the greatest cranial capacity; that of the educated European being about 116 cubic inches, that of the Australian being about 60 cubic inches, a difference of 56 cubic inches. Men distinguished for great mental power usually have large and well-developed brains; that of Cuvier weighed 64 ounces; that of Abercrombie, 63 ounces; the average being about 48 to 50 ounces. Not only in size, but, above all, the texture of the brain must be taken into consideration.

2. *Pathology.*—Any severe injury or disease disorganizing the hemispheres is at once attended by a disturbance or an entire suspension of mental activity. A blow on the head, producing concussion, or undue pressure from cerebral hemorrhages, destroys consciousness; physical and chemic alterations in the gray matter have been shown to coexist with insanity, and with loss of memory, speech, etc. Congenital defects of organization from imperfect development are usually accompanied by a corresponding deficiency of intellectual power and of the higher instincts. Under these circumstances no great advance in mental development can be possible, and the intelligence remains of a low grade. In congenital idiocy not only is the brain of small size, but it is wanting in proper chemic composition, *phosphorus*, a characteristic ingredient of the nervous tissue, being largely diminished in amount.

3. *Experimentation* upon the lower animals—*e.g.*, the removal of the cerebral hemispheres, is attended by results similar to those observed in disease and injury. Removal of the cerebrum in pigeons produces complete abolition of intelligence, and destroys the capability of performing spontaneous movements. The pigeon remains in a condition of profound stupor, which is not accompanied, however, by a loss of sensation or of the power of producing reflex or instinctive movements. The pigeon can be temporarily aroused by pinching the feet, loud noises, lights placed before the eyes, etc., but soon relapses into a state of quietude, being

unable to remember impressions and connect them with any train of ideas, the faculties of memory, reason, and judgment being completely abolished.

4. *Experimental interference* with the blood supply to the cerebrum is followed by a diminished or complete cessation of its activities.

The Localization of Functions in the Cerebrum.—By the term localization of functions is meant the assignment of definite physiologic functions to definite anatomic areas of the cerebral cortex. From experiments made on the brains of animals, by the observation and association of clinical symptoms with pathologic lesions of the central nerve system, and from observation of the developmental stages of the embryonic brain, it has been established in recent years:

1. That the general and special sense-organs of the body are associated through afferent nerve-tracts with definite though perhaps not sharply delimited areas of the cerebral cortex; and—

2. That certain areas of the cortex are associated through efferent nerve-tracts with special groups of skeletal or voluntary muscles.

Experimental excitation of a cortical area associated with a sense-organ is undoubtedly attended by the production of a sensation at least similar to that produced by peripheral excitation of the sense-organ itself; *destruction* of the area is followed by an abolition of all the sensations associated with the sense-organ. For these reasons such areas are termed *sensor*.

Experimental excitation of a cortical area associated with a group of skeletal muscles is attended by their contraction; *destruction* of the area is followed by their relaxation or paralysis. For these reasons such areas are termed *motor*.

The Sensor Areas.—The sensor areas which should theoretically be present in the cortex are primarily those which receive and translate into conscious sensations nerve impulses, developed by changes going on in the body itself; and secondarily those which receive and translate into conscious sensations the nerve impulses developed in the special sense-organs by the impact of the external or objective world. In the former areas, are received the nerve impulses that come from the mucous membranes, muscles, joints, viscera, etc., and give rise to muscle, and visceral sensations. In the latter areas are received the nerve impulses that come from the sense-organs and give rise to cutaneous, gustatory, olfactory, auditory, and visual sensations. A number of such sense areas may be predicated: *e.g.*, areas of *cutaneous* and *muscle sensibility*, of *gustatory*, *olfactory*, and *visual sensibility*.

The sensor areas occupy regions more or less widely separated, though they are associated one with the other by association fibers (Figs, 20, 21).

1. *The Cutaneous Area.*—The area of cutaneous or tactile sensibility has been assigned to the post-central convolution on the lateral aspect, and to a portion of the super-frontal convolution and the lower half of the para-central lobule on the mesial aspect of the hemicerebrum.

Destruction of the post-central convolution in monkeys by the electro-cautery and in man by disease has invariably led to a loss of sensibility, hemianesthesia, on the opposite side of the body without at the same time

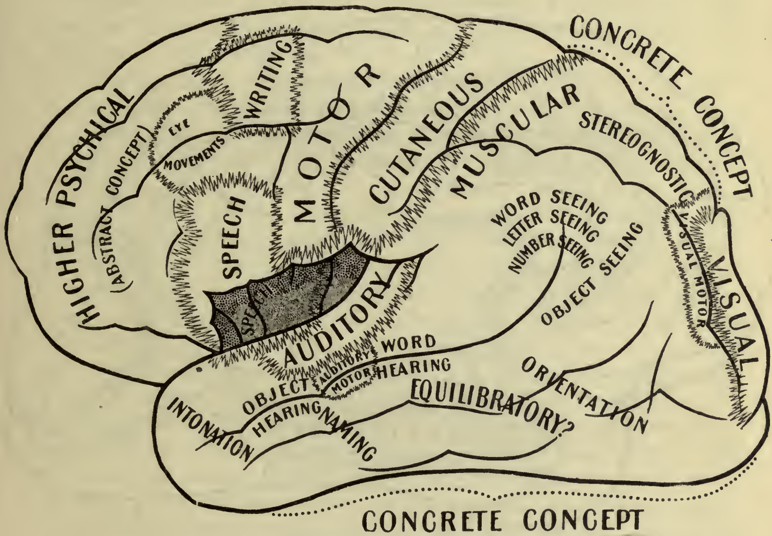

FIG. 20.—THE AREAS AND CENTERS OF THE LATERAL ASPECT OF THE HUMAN HEMICEREBRUM.—(*C. K. Mills.*)

causing any loss of motion. The location and extent of the anesthesia corresponds, of course, with the location and extent of the lesion of the cortex.

2. *The Muscle Sense Area.*—The area of muscle sensibility has been assigned to the region posterior to but adjoining the post-central convolution and includes the anterior part of the super-parietal and sub-parietal convolution and perhaps the supra-marginal convolution on the mesial aspect of the hemicerebrum.

The sensations which are evoked in response to the action of nerve impulses coming from tendons, muscles, etc., are those of passive position and the direction and duration of movements of parts of the body. Clinic observations and post-mortem findings indicate that lesions of this area are followed by a loss of the muscle sense.

In addition to sensations of passive position and direction of movements, the sensations of temperature and deep pressure are also associated with the physiologic activities of this region of the parietal lobe.

3. *The Stereognostic Area.*—The area of stereognostic perception. Stereognostic is the recognition of any object when placed in the hands,

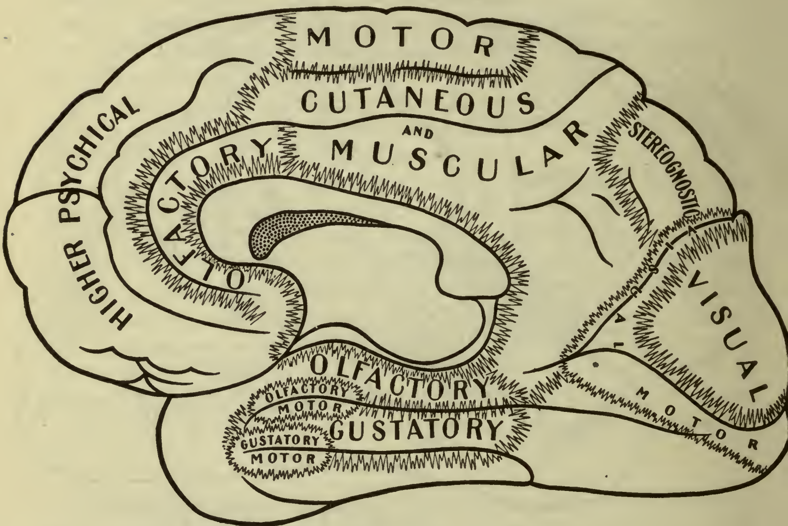

FIG. 21.—THE AREAS AND CENTERS OF THE MESIAL ASPECT OF THE HUMAN HEMICEREBRUM.—(*C. K. Mills.*)

through its form, density, temperature, etc. The area associated with stereognostic perception has been assigned to a portion of the super-parietal convolution and to the precuneus.

A lesion of this area impairs or destroys the power of recognition of objects and establishes the condition of *astereognosis.*

4. *The Gustatory Area.*—The area for gustatory sensibility has been assigned to the sub-collateral convolution on the mesial aspect of the temporo-sphenoidal lobe.

Disease processes involving this area give rise frequently to subjective sensations of taste. Electric stimulation of this area in mammals causes movements of the lips, tongue, etc., which are usually associated with sensations of taste.

5. *The Olfactory Area.*—The area for olfactory sensibility has been assigned to the anterior portion of the hippocampal convolution (the uncinate region) and the anterior portion of the callosal convolution or gyrus fornicatus. Disease processes in this region give rise frequently to subjective sensations of odors which as a rule are of an unpleasant character. Destruction of this area is followed by a loss of odor sensations.

6. *The Auditory Area.*—The area of auditory sensibility has been assigned to portions of the temporal lobe and many be divided into primary and secondary areas.

The primary area is located in the posterior portion of the super-temporal convolution, and perhaps the posterior portion of the insula.

The secondary areas are located one below and in advance and the other below and somewhat behind the primary area, both extending into the medi-temporal convolution.

Unilateral destruction of the primary area is followed, however, only by a partial loss of hearing in the opposite ear, owing to partial decussation of the auditory nerve, which, however, may be recovered from, after a time, owing probably to a compensatory activity of the insular convolution. Bilateral destruction of this region is followed by complete deafness. The primary area is connected on the one hand with the basal auditory center (the internal geniculate body) by the auditory radiation and on the other hand with the secondary areas by association fibers.

In the first of these areas there are cells in which the sounds of objects are registered (object hearing); in the second of these areas there are cells in which the sounds of words, letters, etc., are registered or memorized. If these areas are destroyed by disease the condition of *object-deafness* and *word-deafness* is established. If word-deafness alone exists, the patient though able to recognize sounds is unable to understand spoken language and is in the condition of a man who is hearing a language of which he has not the slightest idea. The same holds true for the perception of sensations of sound produced by objects.

In the temporal lobe there are other areas, some of which are more or less associated with the auditory nerve, such as intonation, equilibratory and orientation areas. (For the afferent pathway to this area, see auditory nerve.)

7. *The Visual Area.*—The area for visual sensibility has been assigned to portions of the occipital and parietal lobes and may be divided into primary and secondary areas.

The primary area is located in a triangular-shaped area on the mesial surface of the occipital lobe, which includes the gray matter above and below the calcarine fissure (the cuneus and upper part of the lingual lobe), and to the gray matter of the first occipital convolution on the lateral aspect of the occipital lobe. Focal lesions of this area on one side are followed by lateral homonymous hemianopsia, which, however, does not involve, as a rule, the fovea or macula. It is, therefore, the area of homonymous half-retinal representation. The location of the area of macular or central vision is near the anterior extremity of the calcarine fissure.

The secondary areas are located partly on the lateral aspect of the occipital lobe and partly in the supra-marginal and angular convolutions of the parietal lobe. The primary area is connected, on the one hand, with the basal visual centers (the external geniculate body and the thalamus) by the optic radiation and, on the other hand, with the secondary areas by association fibers.

The area on the lateral aspect of the occipital lobe is rather extensive, reaching down as far as the third and fourth occipital convolutions. Clinical evidence indicates that the cortex of this entire area is associated with the registration or memorization of the visual sensations and perceptions of objects, though it may be subdivided into smaller areas for the registration of the visual sensations of different groups of objects such as geometric and architectonic forms, of persons, places and natural objects. Diseased processes in this region of the brain may result in the condition known as *object blindness*. The area on the lateral aspect of the parietal lobe (the supra-marginal and angular convolutions) are associated with the memorization of the visual sensations and perceptions of words, letters, numbers, and perhaps objects. If the visual word area is destroyed by disease, *word blindness* is established, and the patient is unable to understand written or printed language because of his inability to revive memory images of words. *Letter* and *number blindness* may or may not be present according to the extent of the lesion. (For the afferent pathway to these areas, see optic nerve.)

The Motor Areas.—The motor areas which should theoretically be present in the cortex are those which in consequence of the discharge of nerve impulses excite contraction of special groups of muscles and which from their coördinate and purposive character, are conventionally termed volitional. Five such general motor areas may be predicated: *e.g.*, one for the muscles of the head and eyes, one for the muscles of the face and associated organs, and others for the muscles of the arm, leg, and trunk.

They are usually designated as *head and eye*, *face*, *arm*, *leg*, and *trunk motor areas*.

The existence and anatomic location of these areas in the cortex of animals have been determined by the employment of two methods of experimentation: viz., stimulation and destruction or extirpation; the first by means of the rapidly repeated induced electric currents, the second by the electric cautery and the knife.

If the stimulation of a given area is attended by phenomena which indicate that the animal is experiencing sensation, and its destruction by a loss of this capability or the loss of a special sense, it is assumed that the area is *sensor* in function—is an *area of special sense.* If the stimulation or excitation of any given area is followed by contraction, and its destruction by paralysis of muscles, it is assumed that the area is *motor* in function—is an *area* of *motion.*

The motor areas are assigned to the precentral convolution, the contiguous portions of the base of the medi- and subfrontal convolutions and the paracentral lobule,

The main motor areas are as follows.

1. *The Head and Eye Area.*—This area has been assigned to the contiguous portions of the medi- and subfrontal convolutions just anterior to the precentral convolution. It is subdivided into smaller areas which initiate and govern the movements of the head and eyeballs. Stimulation of this area, in the chimpanzee at least, produces turning of the head to the opposite side with conjugate deviation of the eyes to that side.

2. *The Face Area.*—This area has been assigned to the lower portion of the precentral convolution and extends from below upward to about the level of the genu of the central fissure. This rather large area may be subdivided into (*a*) an upper portion including about one-third of the whole and (*b*) a lower portion including the remaining two-thirds. In both the upper and lower portions, there are groups of nerve-cells which excite to action, the muscles imparting movements to (*a*) the angle of the mouth, the eyelids and jaws and (*b*) the movements of the vocal bands or cords, the opening and closure of the mouth, the protrusion and retraction of the tongue. All of these movements have their areas of representation in the face area.

3. *The Arm Area.*—This area has been assigned to the precentral convolutions just above and contiguous to the face area which it exceeds somewhat in extent. It is the largest of all the subdivisions of the general area. It may be diviedd into at least five smaller areas, the cells of which excite to action the muscles imparting movements to the thumb, the fingers, the wrist, the elbow and the shoulder.

4. *The Trunk Area.*—This area has been assigned to the precentral convolution just superior to the arm area and is rather limited in extent. Horsely located a portion of this area on the mesial and lateral edges of the hemisphere in front of the leg area. The nerve-cells of this area when electrically stimulated excite to action the muscles, impart movements to the spinal columns, such as arching rotation, etc.

5. *The Leg Area.*—This area has been assigned to the extreme upper portion of the precentral convolution and to the adjoining mesial surface, the upper portion of the paracentral lobule. The area on the lateral aspect of the cerebrum may be subdivided into at least four smaller areas containing groups of nerve-cells which excite to action the muscles imparting movements to the toes, ankle, knee and hip. Evidence from the clinical side has demonstrated the fact that a *localized irritative lesion* of any one of these areas gives rise to convulsive movements of the muscles of the opposite side of the body, similar in character to those resulting from electric simulation of the corresponding areas of the monkey and ape brains. *Destruction* of these areas from the growth of tumors, softening, etc., is followed by paralysis of the muscles. Electric stimulation of these areas of the human brain for the purpose of localizing obscure irritative lesions prior to surgical procedures on the brain gives rise to similar convulsive movements.

The Motor Speech Area.—By this term is meant an area of the cortex, the function of which is to arrange language for outward expression; for the use of the executive centers concerned with speech, *e.g.*, the laryngeal, lingual and facial center located at the foot of the precentral convolution This area, *i.e.*, the motor speech area, has been assigned to the posterior part of the subfrontal convolution (Broca's convolution) on the left side in those who are right-handed and on the right side in those who are congenitally left-handed, and in the anterior part of the insular or perhaps the preinsular convolutions. Unipolar faradic stimulation of this area fails to call forth any motor response; its destruction by disease, however, is followed by a more or less extensive loss of the faculty of articulate speech or the faculty of expressing ideas with words, a condition usually spoken of as motor *aphasia* or *aphemia*. This area and the area at the foot of the precentral convolution are united by association fibers.

The Motor Writing Area.—By this term is meant an area of the cortex, the function of which is to arrange language for outward projection; for the use of the executive centers concerned with writing, viz.: the arm centers located in the middle portion of the precentral convolution. This area, *i.e.*, the motor writing area, has been assigned to the posterior half or third of the medi-frontal convolution. Unipolar faradic stimulation of this area fails to call forth any motor response; its destruction by disease, however, is followed by an inability to express ideas by writing, a condition usually spoken of as *agraphia*. This area and the general arm center in the precentral convolution are united by association fibers.

THE CEREBELLUM

The cerebellum is situated in the inferior fossæ of the occipital bone, beneath the posterior lobes of the cerebrum. It attains its maximum

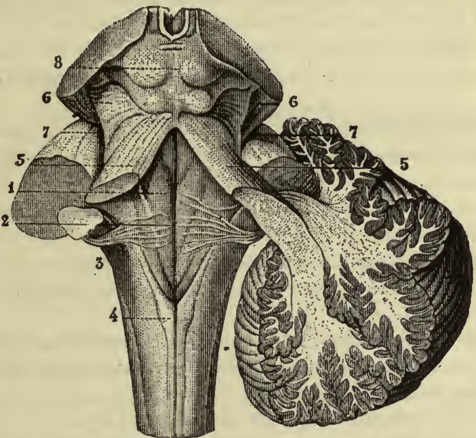

FIG. 22.—VIEW OF CEREBELLUM IN SECTION AND OF FOURTH VENTRICLE, WITH THE NEIGHBORING PARTS.—(*From Sappey.*)

1. Median groove fourth ventricle, ending below in the calamus scriptorius, with the longitudinal eminences formed by the fasciculi teretes, one on each side. 2. The same groove, at the place where the white streaks of the auditory nerve emerge from it to cross the floor of the ventricle. 3, Inferior peduncle of the cerebellum, formed by the restiform body. 4. Posterior pyramid; above this is the calamus scriptorius. 5, 5. Superior peduncle of cerebellum, or processus e cerebello and testes. 6, 6. Fillet to the side of the crura cerebri. 7, 7. Lateral grooves of the crura cerebri. 8. Corpora quadrigemina.—(*After Hirschfeld and Leville.*)

weight, which is about one hundred and forty grams, between the twenty-fifth and fortieth years.

It is composed of *two lateral hemispheres* and a central elongated lobe, the *vermiform process;* the two hemispheres are connected with each other by the fibers of the *middle peduncle*, forming the superficial portion of the pons Varolii. The cerebellum is brought into connection with the *medulla oblongata* and *spinal cord* through the prolongation of the *restiform* bodies;

with the cerebrum, by fibers passing upward beneath the corpora quadrigemina and the optic thalami, and then forming part of the diverging cerebral fibers.

Structure.—It is composed of both white and gray matter, the former being internal, the latter external, and is convoluted, for economy of space.

The *white matter* consists of a central stem, the interior of which is a dentated capsule of gray matter, the *corpus dentatum*. From the external surface of the stem of white matter processes are given off, forming the *laminæ*, see Fig. 22, which are covered with gray matter.

The *gray matter* is convoluted and covers externally the laminated processes; a vertical section through the gray matter reveals the following structures:

1. A delicate *connective-tissue layer*, just beneath the pia mater, containing rounded corpuscles, and with branching fibers passing toward the external surface.

2. *The cells of Purkinje*, forming a layer of large, nucleated, branched nerve-cells sending off processes to the external layer.

3. A *granular layer* of small but numerous corpuscles.

4. A *nerve-fiber layer*, formed by a portion of the white matter.

Properties and Functions.—Irritation of the cerebellum is not followed by any evidences either of pain or convulsive movements; it is, therefore, *insensible* and *inexcitable*.

Coördination of Movements.—Removal of the superficial portions of the cerebellum in pigeons produces *feebleness* and *want of harmony* in the muscular movements; as successive slices are removed, the movements become more irregular, and the pigeon becomes restless; when the last portions are removed, all power of *flying*, *walking*, *standing*, etc., is entirely gone, and the *equilibrium* cannot be maintained, the power of *coördinating* muscular movements being wholly lost. The same results have been obtained by operating on all classes of animals.

The following symptoms were noticed by Wagner, after removing the whole or a large part of the cerebellum:

1. A tendency on the part of the animal to throw itself on one side, and to extend the legs as far as possible.

2. Torsion of the head on the neck.

3. Trembling of the muscles of the body, which was general.

4. Vomiting and occasional liquid evacuations.

Forced Movements.—Division of *one crus cerebelli* causes the animal to fall on one side and roll rapidly on its longitudinal axis. According to Schiff, if the peduncle be divided from *behind*, the animal falls on the same side as the injury; if the section be made in *front*, the animal turns to the opposite side.

Disease of the cerebellum partially corroborates the result of experiments; in many cases symptoms of unsteadiness of gait, from a *want of coördination*, have been noticed.

Comparative anatomy reveals a remarkable correspondence between the development of the cerebellum and the increase in complexity of muscular actions. It attains a much greater development, relatively to the rest of the brain, in those animals whose movements are very complex and varied in character, such as the kangaroo, shark, and swallow.

THE AUTONOMIC NERVE SYSTEM

The Autonomic nerves comprise all the nerves that are distributed to the non-striated muscle-fibers in the walls of the blood-vessels, in the walls of the viscera and to the epithelium of all glands. These nerves consist of two consecutively arranged neurons, the first of which arises in the central nerve system and is termed preganglionic; the second of which arises in ganglionic cells and is, therefore, termed postganglionic Inasmuch as the central nerve-cells giving origin to the preganglionic fibers are independent of volitional control (in marked contrast to the nerve-cells giving origin to the fibers for skeletal muscles) this system of nerves possesses a certain degree of autonomy, and has been termed the autonomic system. Though independent of volitional control they are influenced in the way of increased or decreased activity, by psychic states of an affective or emotional character. Their activity, however, is mainly excited by nerve impulses transmitted to them from the surfaces of the body.

The Physiologic Anatomy of the Autonomic Nerve System.—In a consideration of the essential facts of the physiologic anatomy of this system it will be convenient to consider first, the sympathetic ganglia and the distribution of their postganglionic fibers.

The Sympathetic Ganglia.—These ganglia may be divided into 3 groups, viz: the *vertebral*, the *prevertebral* and the *peripheral*. From each of these groups non-medullated nerve-fibers pass in different directions. The *vertebral ganglia* give off fibers which under the name *gray rami communicantes* pass backward into the trunks of the spinal nerves and are distributed to the blood-vessels of the skin of the trunk, arms and legs, as well as to the epithelium of the sweat-glands of the corresponding regions.

The fibers of the upper cervical ganglia pass directly to the blood-vessels and sweat-glands of the head and face, while others pass directly to viscera, as the heart. All fibers going direct to their destination are termed *rami viscerales.*

The *prevertebral ganglia,* the semilunar, the renal, the superior and inferior mesenteric, give off fibers which pass to the walls of the blood-vessels and to the viscera of the stomach, intestine, gall-bladder, liver, kidney and pelvic viscera, etc.

The *peripheral ganglia,* the ciliary, the spheno-palatine, the otic, the submaxillary, the cardiac, pelvic, etc., give off branches which pass to the non-striated muscle fibers in the organs to which they are in anatomic relation.

From the distribution of the branches emerging from all the different groups of ganglia, there is reason to believe that they are directly associated with *vaso-augmentor* and *vaso-inhibitor*, *viscero-augmentor* and *viscero-inhibitor*, *secreto-motor* and *secreto-inhibitor* phenomena.

The Anatomic Relation of the Central Nerve System to the Sympathetic Ganglia.—The central nerve system is associated anatomically and physiologically with the sympathetic ganglia through the intermediation of fine medullated nerve-fibers, the preganglionic, which have their origin in nerve-cells situated in four different regions, viz.:

1. **The Mid-brain Region.**—The preganglionic nerve-fibers that leave the brain in this region arise from groups of nerve-cells situated high up in the gray matter beneath the aqueduct of Sylvius just where it widens to form the cavity of the third ventricle. From this origin they enter the trunk of the oculo-motor nerve and in association with it enter the orbit cavity. In this situation these preganglionic fibers leave the oculo-motor nerve and enter the ciliary or ophthalmic ganglion around the nerve-cells of which their terminal branches arborize. The gray postganglionic fibers arising in the gray cells of this ganglion enter the eyeball and are ultimately distributed to the sphincter muscle of the iris and to the ciliary muscle.

2. **The Bulbar Region.**—The preganglionic fibers that leave the brain in this region arise from nerve-cells situated in the gray matter beneath the floor of the fourth ventricle a little above and below the calamus scriptorius. These fibers leave this region by three routes, viz.:

(*a.*) By way of the nerve of Wrisberg or the *pars intermedia.* The preganglionic fibers that emerge in this nerve enter the facial nerve and subsequently pass by way of the great superficial petrosal nerve to the sphenopalatine ganglion, and by the way of the chorda tympani nerve to the sub-maxillary ganglion, around the nerve-cells of which their terminal branches arborize. The gray postganglionic fibers which arise in the cells of these ganglia are distributed to the blood-vessels and glands of the nose and mouth and to the blood-vessels and epithelium of the submaxillary and sublingual glands respectively.

(*b.*) By way of the glosso-pharyngeal nerve. The fibers that emerge in this nerve pass into the tympanic branch or nerve of Jacobson and ultimately arborize around the cells of the otic ganglion. The gray postganglionic fibers which arise in the cells of this ganglion pass by way of the auriculo-temporal branch of the trigeminal nerve to the blood-vessels and epithelium of the parotid gland.

(*c.*) By way of the vagus nerve. The preganglionic fibers that leave in the trunk of the vagus nerve are ultimately distributed to the ganglia of the heart, stomach, small intestine, etc., around the nerve-cells of which their terminal branches arborize. The gray postganglionic fibers which arise in these ganglia pass to the heart-fibers, to the non-striated muscle-fibers in the walls of the stomach, intestines, etc. These fibers contained in the facial, glosso-pharyngeal and vagus nerves, together with their ganglionic continuations, have collectively been termed the *bulbar autonomic* system. Together with the fibers in the oculo-motor nerve they have been termed the *cranio-bulbar* autonomic system.

3. **The Mid-spinal Cord Region**—The preganglionic nerve-fibers that leave the spinal cord in this region arise from groups of nerve-cells situated in the gray matter between the levels of origin of the second thoracic and the second and third, perhaps the fourth, lumbar nerves. From this origin the fine pre-ganglionic fibers emerge from the cord in the ventral roots of the thoracic and upper lumbar nerves and hence naturally fall into two groups, viz.: the thoracic and the lumbar. Both groups of nerves accompany the ventral motor roots of the spinal nerves to about the point where each nerve divides into an anterior and a posterior branch; they then leave and enter the vertebral chain of ganglia. The branches of communication are known as the *white rami communicantes.* The nerve-fibers composing these communicating branches terminate for the most part around the nerve-cells of the ganglia at the same and at somewhat different levels and in different regions.

Some of the fibers of the thoracic group, however, cross the vertebral chain and then pass forward and downward, uniting to form the *greater* and *lesser splanchnic nerves,* the terminal branches of which arborize around the cells of the semilunar, the renal and the superior mesenteric ganglia. Some of the lumbar nerves also pass across the vertebral chain to form the *inferior splanchnic nerves*, the terminal branches of which arborize around the cells of the inferior mesenteric ganglion.

The distribution of the postganglionic fibers has already been alluded to. The preganglionic nerve-fibers having their origin in the mid-spinal cord region comprise all the vaso-motor (constrictor) nerves, the secreto-motor (sweat) nerves and the viscero-inhibitor nerves for the stomach, intestines and other viscera, as well as some viscero-motor fibers. These nerves collectively constitute the *thoracico-lumbar autonomic* nerve system.

4. **The Sacral Spinal-cord Region.**—The preganglionic nerve-fibers that leave the spinal cord in this region arise from groups of nerve-cells situated in the gray matter between and including the levels of origin of the second, the third and the fourth (?) sacral nerves. From this origin the preganglionic fibers emerge from the cord in association with the large motor fibers composing the ventral roots of these sacral nerves and pass with them to the interior of the pelvis. Here they leave the sacral nerves and enter the pudendal or pelvic nerve (the nervus erigens) and finally terminate around the cells of the pelvic ganglia. From these ganglia postganglionic fibers arise which pass onward to be distributed to the non-striated muscle-fibers of pelvic viscera and the blood-vessels of the external generative organs. These fibers contained in the sacral nerves together with their post-ganglionic continuation have collectively been termed the *sacral autonomic* system. It may be regarded as a special nerve system for the anal end of the gut and structures developmentally connected with it.

The Functions of the Autonomic Nerve System.—The functions of the autonomic nerve system, as determined from its anatomic distribution, and the results of experimental investigations, are to *augment* or to *inhibit* the tonus of the blood-vessels including the heart, the tonus of visceral walls and the activity of the epithelium of glands, and are, therefore, the sum total of the functions of the vaso-motor, viscero-motor and secreto-motor nerves, that is, the nerves which collectively constitute this system.

In the various sections of the text specific statements are to be found as to the functions of the autonomic nerves in association with the oculomotor nerve, the nerve of Wrisberg, (the great petrosal and chorda tympani fibers) the glosso-pharyngeal nerve (Jacobson's nerve) the vagus nerve (the cardiac, bronchial, gastric and intestinal fibers) the thoracico-lumbar nerves (the vaso-motor, viscero-motor, secreto-motor, and cardiac accelerator fibers) the sacral nerves (the vaso-dilatator and viscero-motor, and inhibitor fibers for the pelvic viscera and external organs of generation.

THE CRANIAL NERVES

The cranial nerves come off from the base of the brain, pass through foramina in the walls of the cranium, and are distributed to the structures of the head, the face and in part to the organs of the thorax and abdomen.

According to the classification of Soemmering, there are twelve pairs of nerves, enumerating them from before backward, as follows—viz.:

First nerve, or olfactory.
Second nerve, or optic.
Third nerve, or motor oculi communis.
Fourth nerve, or trochlearis.
Fifth nerve, or trigeminal.
Sixth nerve, or abducent.
Seventh nerve, or facial, portio dura.
Eighth nerve, or acouctic.
Ninth nerve, or glosso-pharyngeal.
Tenth nerve, or pneumogastric.
Eleventh nerve, or spinal accessory.
Twelfth nerve, or hypoglossal.

The **cranial nerves** may also be classified physiologically, according to their function, into three groups:

1. Nerves of special sense—*e.g.*, olfactory, optic, acoustic, gustatory, glosso-pharyngeal and chorda tympani).

2. Nervous of Motion—*e.g.*, motor oculi, pathetic, small root of the trigeminal, abducent, facial, spinal accessory and hypoglossal.

3. Nerves of general sensibility—*e.g.*, large root of the trigeminal, the glosso-pharyngeal and the pneumogastric.

ORIGINS OF THE CRANIAL NERVES

The *nerves of special sense* have their origin in neuro-epithelial cells in the sense organs with which they are connected.

The *nerves of motion* have their origin in nerve-cells situated in the gray matter beneath the floor of the aqueduct of Sylvius and the floor of the fourth ventricle.

The *nerves of general sensibility* have their origin in the ganglia situated on their trunks.

First Nerve—Olfactory

The olfactory nerve is situated in the upper third of the nasal fossa. It consists of from 20 to 30 branches.

Origin.—From neuro-epithelial cells situated among the epithelial cells covering the mucous membrane. From these cells the nerve-fibers pass upward through foramina in the cribriform plate of the ethmoid bone and arborize around nerve-cells, in the olfactory bulb.

The Olfactory Tract.—The olfactory tract consists of both gray and white fibers which pass from their origin in the bulb, to the base of the cerebrum where it divides three branches, viz.: an *external white root*, which passes across the fissure of Sylvius to the middle lobe of the cerebrum; an *internal white root*, which passes also into the middle lobe; a *gray root*, which is in relation with the anterior lobe. The white fibers at least terminate around nerve-cells in the gray matter of the pre-callosal part of the gyrus fornicatus, the gyrus hippocampus and the gyrus uncinatus.

Properties.—The olfactory nerves do not give rise to either motor or sensor phenomena when stimulated. When stimulated at their periphery by odorous particles, nerve impulses are developed which, when conducted to the brain, evoke the sensation of smell. Destruction of the olfactory nerves, the bulb or tract, is followed by a loss of the sense of smell.

Function.—Presides over the sense of smell. Conducts impulses to the cerebrum which give rise to sensations of odor.

Second Nerve—Optic

Origin.—The optic nerve arises from large nerve-cells in the anterior part of the retina. From this origin the nerve-fibers turn backward and converge to form a well-defined bundle (the optic nerve) which passes out of the eyeball, through the orbit cavity as far as the sella turcica. At this point there is a union and partial decussation, in man at least, of the fibers, forming what is known as the *optic chiasm*. From the posterior portion of the chiasm there passes backward on either side a bundle of nerve-fibers, the *optic tract*. Each tract contains nerve-fibers, which come from the temporal two-thirds of the retina of the same side and the nasal third of the retina of the opposite side. The fibers of the optic tract arborize around nerve-cells in the external geniculate body, the pulvinar, and the anterior quadrigeminal body. By means of the optic radiation, the nerve-cells in these different ganglia are brought into relation with the visual center, the *cuneus*.

Properties.—The optic nerves are insensible to ordinary impressions, and convey only the *special impressions of light*. *Division* of one of the nerves is attended by complete blindness in the eye of the corresponding side.

Hemiopia and Hemianopsia.—Owing to the decussation of the fibers in the optic chasm, *division* of the *optic tract* produces *loss* of *sight* in the *outer half* of the eye of the same side, and in the *inner half* of the eye of the opposite side, the blind part being separated from the normal part by a vertical line. The term hemiopia is applied to the loss of function or paralysis of the one-half of the retina; as a result of this, there will be an obliteration of the field of vision on the opposite side to which the term hemianopsia is given. If, for example, the *right optic tract* be divided, there will be hemiopia in the outer half of the right eye and inner half of the left eye, thus causing *left lateral hemianopsia*, and as the two halves are affected which correspond in normal vision, the condition is known as *homonymous hemianopsia.* Lesion of the anterior part of the *optic chiasm* caused blindness in the inner half of the two eyes.

Functions.—Governs the sense of sight. Receives and conveys to the brain the nerve impulses made by ether vibrations and which give rise to the sensation of light.

The reflex movements of the iris are called forth by stimulation of the optic nerve. When light falls upon the retina, the nerve impulse developed is carried back to the tubercula quadrigemina, where it is transformed into a motor impulse, which then passes outward through the motor oculi nerve to the contractile fibers of the iris and diminishes the size of the pupil. The absence of light is followed by a dilatation of the pupil.

Third Nerve—The Oculo-Motor

Origin.—From several groups of nerve-cells situated in the gray matter beneath the aqueduct of Sylvius.

Distribution.—From this origin the nerve-fibers pass forward and emerge from the cerebrum at the inner side of the crus cerebri. The nerve then passes forward, and enters the orbit through the sphenoid fissure, where it divides into a *superior branch* distributed to the *superior rectus* and *levator palpebræ* muscles; and *inferior* branch, sending branches to the *internal* and *inferor recti* and the *inferior oblique* muscles; filaments also pass into the *cilary* or *pathalmic* ganglion; from this ganglion the *ciliary nerves* arise, which enter the eyeball and are distributed to the *circular fibers of the iris* and the *ciliary muscle.* This third nerve also receives filaments from the cavernous plexus of the sympathetic and from the fifth nerve.

Properties.—Irritation of the root of the nerve produces contraction of the pupil, internal strabismus, and muscular movements of the eye, but no pain. *Division* of the nerve is followed by *ptosis* (falling of the upper eyelid); *external strabismus,* due to the unopposed action of the external rectus muscle; paralysis of the accommodation of the eye; *dilatation* of the pupil from paralysis of the circular fibers of the iris and ciliary muscle; and *inability* to *rotate* the eye, *slight protrusion*, and *double vision.* The images are crossed; that of the paralyzed eye is a little above that of the second, and its upper end inclined toward it.

Function.—Governs movements of the eyeball by innervating all the muscles except the external rectus and superior oblique, influences the movements of the iris, elevates the upper lid, influences the accommodation of the eye for distances. Can be called into action by (1) voluntary stimuli, (2) by reflex action through irritation of the optic nerve.

Fourth Nerve—Trochlearis

Origin.—From nerve-cells situated in the gray matter beneath the aqueduct of Sylvius, just posterior to the last nucleus of the third nerve.

Distribution.—The nerve enters the orbitial cavity through the sphenoid fissure and is distributed to the *superior oblique* muscle; in its course it receives filaments from the ophthalmic branch of the fifth pair and the sympathetic.

Properties.—When the nerve is *irritated*, muscular movements are produced in the superior oblique muscle, and the pupil of the eye is turned *downward* and *outward.* Division or paralysis lessens the movements and rotation of the globe downward and outward. The diplopia consequent upon this paralysis is homonymous, one image appearing above the other. The image of the paralyzed eye is below, its upper end inclined toward that of the sound eye.

Function.—Governs the movements of the eyeball produced by the action of the superior oblique muscles.

Sixth Nerve*—Abducent

Origin.—From nerve -cells situated beneath the upper half of the floor of the fourth ventricle.

Distribution.—From this origin the nerve passes into the orbit through the sphenoid fissure, and is distributed to the *external rectus* muscle. Receives filaments from the cervical portion of the sympathetic, through the carotid plexus, and spheno-palatine ganglion.

*The sixth nerve is considered in connection with the third and fourth nerves since they together constitute the motor apparatus by which the ocular muscles are excited to action.

Properties.—When *irritated*, the *external rectus muscle* is thrown into convulsive movements and the eyeball is turned outward. When *divided* or *paralyzed*, this muscle is paralyzed, motion of the eyeball outward past the median line is impossible, and the homonymous diplopia increases as the object is moved outward past this line. The images are upon the same plane and parallel. Internal strabismus results because of the unopposed action of the internal rectus.

Function.—To innervate the external rectus muscle by which the eyeball is turned outward.

Fifth Nerve—Trigeminal

The fifth nerve consists of both afferent and efferent fibers which for the most part are separate and distinct. The afferent fibers constitute by far the major portion, the efferent fibers the minor portion of the nerve.

Origin of the Afferent Fibers.—The afferent fibers have their origin in nerve-cells in the Gasserian ganglion. From each cell a short process develops which soon divides into two branches, one of which passes centrally, the other peripherally. The centrally directed branches form the so-called large root; the peripherally directed branches collectively constitute the three main divisions of the nerve, viz.: the ophthalmic, the superior maxillary and the inferior maxillary.

Distribution.—The *centrally directed* branches enter the pons Varolii on its lateral aspect. After pursuing a short distance, these fibers arborize around nerve-cells in the gray matter of the pons and medulla.

The *peripherally directed* branches are distributed as follows:

1. The *ophthalmic branches* to the conjunctiva and skin of the upper eyelid, the cornea, the skin of the forehead and the nose, the lachrymal gland and the mucous membrane of the nose.

2. The *superior maxillary branches* to the skin and conjunctiva of the lower lid, the nose, the cheek and upper lip, the palpate teeth of the upper jaw and the alveolar processes.

3. The *inferior maxillary branches* to the external auditory meatus, the side of the head, the mouth, the tongue, the teeth of the lower jaw, the alveolar processes and the skin of the lower part of the face.

Properties.—The trigeminal nerve, composed mainly of afferent fibers, is the most acutely sensitive nerve in the body, and endows all the parts to which it is distributed with general sensibility.

Stimulation of the *large root*, or of any of its branches, will give rise to marked evidence of pain; the various forms of neuralgia of the head and face being occasioned by compression, disease, or exposure of some of its terminal branches.

Division of the large root within the cranium is followed at once by a complete abolition of all sensibility in the head and face, but is not attended by any loss of motion. The integument, the mucous membranes, and the eye may be lacerated, cut, or bruised, without the animal exhibiting any evidence of pain. At the same time the lachrymal secretion is diminished, the pupil becomes contracted, the eyeball is protruded, and the sensibility of the tongue is abolished.

The reflex movements of deglutition are also somewhat impaired, the impressions of the food being unable to reach and excite the nerve center in the medulla oblongata.

Origin of the Efferent Fibers.—The efferent fibers have their origin in nerve-cells in the gray matter of the pons Varolii beneath the floor of the fourth ventricle.

Distribution.—The efferent fibers, known collectively as the small root, emerge from the side of the pons Varolii, pass forward beneath the ganglion of Gasser, beyond which they enter the inferior maxillary division. After a short course most of these fibers leave the common trunk and are distributed to the muscles of mastication, viz.: the temporal, the masseter, the internal and external pterygoid muscles. Other fibers are distributed to the mylohyoid muscle, the tensor palati and the tensor tympani muscles.

Properties.—*Stimulation* of the *small root* produces convulsive movements of the muscles of mastication; *section* of the root causes paralysis of these muscles, after which the jaw is drawn to the opposite side by the action of the opposing muscles.

The Influence of the Trigeminal on the Special Senses.—After division of the large root within the cranium, a disturbance in the nutrition of the special senses sooner or later manifests itself.

Sight.—In the course of twenty-four hours the *eye* becomes very vascular and inflamed, the cornea becomes opaque and ulcerates, the humors are discharged, and the eye is totally destroyed.

Smell.—The nasal mucous membrane swells up, becomes fungous, and is liable to bleed on the slightest irritation. The mucus is increased in amount, so as to obstruct the nasal passages; the sense of smell is finally abolished.

Hearing.—At times the hearing is impaired from disorders of nutrition in the middle ear and external auditory meatus.

Alteration in the nutrition of the special senses is not marked if the section is made posterior to the ganglion of Gasser and to the anastomosing filaments of the sympathetic, which joins the nerves at this point; but if the ganglion be divided, these effects are very noticeable, owing to the section of the sympathetic filaments.

Function.—The trigeminal nerve, through its afferent fibers, endows all the parts of the head and face to which it is distributed with sensibility; through its efferent fibers it gives motion to the muscles of mastication, and to the tensor muscle of the palate and the tensor of the tympanic membrane; through anastomosing fibers from the sympathetic it influences the nutrition of the special senses.

Seventh Nerve—Facial Nerve

Origin.—From a large nucleus of nerve-cells situated in the gray matter beneath the upper half of the floor of the fourth ventricle.

Distribution.—From this origin the nerve emerges from the lower border of the pons. It then passes into the internal auditory meatus in company with the nerve of Wrisberg, and then enters the aqueduct of Fallopius.

The nerve-fibers composing the nerve of Wrisberg have their origin in nerve-cells in the geniculate ganglion, situated on the facial just where it bends to enter the aqueduct of Fallopius. The centrally directed branches enter the medulla oblongata around the nerve-cells of which they terminate; the peripherally directed branches enter the trunk of the facial.

In the aqueduct the facial gives off the following branches—viz.:

1. The *large petrosal nerve*, which passes forward to the *splenopalatine*, or Meckel's ganglion.

2. The *small petrosal nerve*, which passes to the *otic* ganglion.

3. The *tympanic branch*, which passes to the stapedius muscle and endows it with motion.

4. The *chorda tympani nerve*, which, after entering the posterior part of the tympanic cavity, passes forward between the malleus and incus, through the Glasserian fissure, and joins the lingual branch of the fifth nerve. It is then distributed to the mucous membrane of the anterior two-thirds of the tongue and the submaxillary glands.

After emerging from the stylomastoid foramen, the facial nerve sends branches to the muscles of the ear, the occipitofrontalis, the digastric, the palatoglossi, and palatopharyngeal; after which it passes through the parotid gland and divides into the *temporofacial* and *cervicofacial* branches, which are distributed to the superficial muscles of the face—viz., occipito-frontalis, corrugator supercilii, orbicularis palpebrarum, levator labii superioris et alæque nasi, buccinator, levator anguli oris, orbicularis oris, zygomatici, depressor anguli oris, platysma myoides, etc.

Properties.—The facial is a motor nerve at its origin, but in its course receives sensitive filaments from the fifth pair and the pneumogastric.

Stimulation of the nerve, after its emergence from the stylomastoid foramen, produces convulsive movements in all the superficial muscles of the face. *Divisior* of the nerve at this point causes paralysis of these muscles on the side of the section, constituting *facial paralysis*, the phenomena of which are a relaxed and immobile condition of the same side of the face, the eyelids remain open, from paralysis of the orbicularis palpebrarum; the act of winking is abolished; the angle of the mouth droops, and saliva constantly drains away; the face is drawn over to the second side; the face becomes distorted upon talking or laughing; mastication is interfered with, the food accumulating between the gums and cheek, from paralysis of the buccinator muscle; fluids escape from the mouth in drinking; articulation is impaired, the labial sounds being imperfectly pronounced.

Properties and Functions of the Branches Given off in the Aqueduct of Fallopius.

1. The *large petrosal*, when stimulated, gives rise to a dilatation of the blood-vessels and a secretion from the mucous membrane of nose, soft palate, upper part of the pharynx, roof of the mouth, and gums. It therefore contains vaso-motor and secretor fibers,which are in relation with the spheno-palatine ganglion.

2. The *tympanic* branch causes the stapedius muscle to contract.

3. The *chorda tympani* influences the circulation of the blood around, and the secretion of saliva from, the submaxillary glands, and through the nerve of Wrisberg endows the anterior two-thirds of the tongue with the sense of taste. *Stimulation* of the chorda tympani dilates the blood-vessels, increases the quantity and rapidity of the stream of blood, and increases the secretion of saliva. *Division* of the nerve is followed by contraction of the vessels, and arrest of the secretion, and a loss of the sense of taste on the same side. It therefore contains vaso-motor, secretor and gustatory nerve-fibers.

Function.—The facial is the nerve of expression, and coördinates the muscles employed to delineate the various emotions, influences the sense of taste and the secretions of the submaxillary and sublingual glands.

Eighth Nerve—Acoustic Nerve

The eighth nerve consists of two portions, a *cochlear* or *auditory* and a *vestibular* or *equilibratory*.

Origin.—The cochlear portion and its origin in the bipolar nerve-cells of the spinal ganglion located in the spiral canal near the base of the osseous lamina spiralis. The vestibular portion has its origin in the bipolar nerve-cells of the ganglion of Scarpa located in the internal auditory meatus.

Distribution.—The common trunk of the eighth nerve, consisting of both the cochlear and vestibular portions, emerges from the internal auditory meatus, after which it passes backward and inward as far as the lateral aspect of the pons, where the two main divisions again separate. The cochlear portion passes to the outer side of the restiform body; the vestibular portion passes to the inner side of the restiform body to the dorsal portion of the pons. After entering the pons the fibers composing both portions come into histologic relations with different groups of nerve-cells.

Properties.—Stimulation of the cochlear nerve is unattended by either motor or sensor phenomena. Division of the nerve is followed by a loss of hearing. Destruction of the semicircular canal, involving a lesion of the vestibular nerves at their origin, is followed by an impairment of the power of coördination and equilibration.

Functions.—The cochlear nerve presides over the sense of hearing. It carries to the brain the nerve impulses produced by the impact of atmospheric vibrations on the ear, and which give rise to the sensation of sound. The vestibular nerve carries nerve impulses to the brain, which excite certain reflex adaptive movements by which the equilibrium of the body is maintained.

Ninth Nerve—Glossopharyngeal

Origin.—From nerve-cells in the ganglia situated on the trunk of the nerve near the medulla oblongata—viz., the petrosal ganglion and the jugular ganglion. From these cells a single branch emerges, which soon divides into two branches, one of which passes centrally, the other peripherally. The centrally directed branches enter the medulla oblongata, where they terminate around nerve-cells. The peripherally directed branches collectively form the two main divisions from which the nerve takes its name.

The glossopharyngeal also contains efferent nerve-fibers, which have their origin in nerve-cells beneath the floor of the fourth ventricle.

Distribution—The trunk of the nerve passes downward and forward, receiving near the jugular ganglion fibers from the facial and pneumogastric nerves. It divides into two large branches, one of which is distributed to the base of the tongue, the other to the pharynx. In its course it sends filaments to the otic ganglion; a tympanic branch which gives sensibility to the mucous membrane of the fenestra rotunda, fenestra ovalis, and Eustachian tube; lingual branches to the base of the tongue; palatal branches to the soft palate, uvula, and tonsils; pharyngeal branches to the mucous membrane of the pharynx.

Properties—*Irritation* of the roots at their origin calls forth evidences of pain; it is, therefore, a sensor nerve, but its sensibility is not so acute as that of the trigeminal. *Irritation* of the trunk after its exit from the cranium produces contraction of the muscles of the palate and pharynx, owing to the presence of motor fibers.

Division of the nerve abolishes sensibility in the structures to which it is distributed and impairs the sense of taste in the posterior third of the tongue (see Sense of Taste).

Function—Governs the sensibility of the pharynx, presides partly over the sense of taste, and controls reflex movements of deglutition and vomiting.

Tenth Nerve—Pneumogastric. Vagus

Origin.—From the nerve-cells situated along the trunk of the nerve near the medulla oblongata—viz.: the jugular and the plexiform ganglia. From the nerve-cells in these ganglia a short process emerges which soon divides into two branches one of which passes centrally, the other peripherally. The central branches enter the medulla oblongata, where they terminate around nerve-cells; the peripheral branches collectively form the main portion of the trunk of the nerve.

The pneumogastric also contains efferent fibers which have their origin in nerve-cells beneath the floor of the medulla oblongata. It also receives motor fibers from the spinal accessory, the facial, the hypoglossal and the anterior branches of the two upper cervical nerves.

Distribution.—As the nerve passes down the neck it sends off the following main branches:

1. *Pharyngeal nerves*, which assist in forming the pharyngeal plexus which is distributed to the mucous membrane and to the muscles of the pharynx.

2. *Superior laryngeal nerve*, which enters the larynx through the

thyrohyoid membrane, and is distributed to the mucous membrane lining the interior of the larynx, and to the cricothyroid muscle and the inferior constrictor of the pharynx. The "*depressor nerve*," found in the rabbit, is formed by the union of two branches, one from the superior laryngeal, the other from the main trunk; it passes downward to be distributed to the heart.

3. *Inferior laryngeal*, which sends its ultimate branches to all the intrinsic muscles of the larynx except the cricothyroid, and to the inferior constrictor of the pharynx.

4. *Cardiac* branches given off from the nerve throughout its course which unite with the sympathetic fibers to form the cardiac plexus, to be distributed to the heart.

5. *Pulmonary branches*, which form a plexus of nerves, and are distributed to the bronchi and their ultimate terminations, the lobules and air cells.

From the right pneumogastric nerve branches are distributed to the mucous membrane and the muscular coats of the stomach and intestines, and to the liver, spleen, kidneys, and suprarenal capsules.

Properties.—At its origin the pneumogastric nerve is sensory, as shown by direct irritation or galvanization, though its sensibility is not very marked. In its course it exhibits motor properties, from anastomosis with motor nerves.

The *pharyngeal branches* assist in giving sensibility to the mucous membrane of the pharynx, and influence reflex phenomena of deglutition through motor fibers which they contain, derived from the spinal accessory.

The *superior laryngeal* nerve endows the upper portion of the larynx with sensibility; protects it from the entrance of foreign bodies; by conducting impressions to the medulla, excites the reflex movements of deglutition and respiration; through the motor filaments it contains, produces contraction of the cricothyroid muscle.

Division of the "*depressor nerve*," and *stimulation* of the central end retard the pulsations of the heart, and by depressing the vaso-motor center, diminish the pressure of blood in the large vessels, by causing dilatation of the intestinal vessels through the splanchnic nerves.

The *inferior laryngeal* contains, for the most part, motor fibers from the spinal accessory. When *irritated*, produces movement in the laryngeal muscles. When *divided*, is followed by paralysis of these muscles, except the cricothyroid, impairment of phonation, and an embarrassment of the respiratory movement of the larynx, and, finally, death from suffocation.

The *cardiac branches*, through filaments derived from the spinal accessory, or possibly from the medulla oblongata direct, exert a direct inhibitory action upon the heart. *Division* of the pneumogastrics or vagi in the neck is followed by increased frequency of the heart's action. *Stimulation* of the peripheral ends diminishes the heart's pulsations, and, if sufficiently powerful, arrests it in diastole.

The *pulmonary branches* give sensibility to the bronchial mucous membrane and govern the movements of respiration. *Division* of both pneumogastrics in the neck diminishes the frequency of the respiratory movements, which may fall as low as four to six a minute; death usually occurs in from five to eight days. *Feeble stimulation* of the central ends of the divided nerves accelerates respiration, *powerful stimulation* retards, and may even arrest the respiratory movements.

The *gastric branches* give sensibility to the mucous coat, and through motor or efferent fibers give motion to the muscular coat of the stomach. They influence the secretion of gastric juice, and aid the process of digestion.

The *intestinal branches* give sensibility and motion to the small intestines.

Function.—A great sensor nerve, which, through filaments from motor sources, influences deglutition, the action of the heart, the circulatory and respiratory systems, voice, the secretions of the stomach, intestines and various glandular organs, and the contraction of the walls of the stomach and intestines.

Eleventh Nerve—Spinal Accessory

The spinal accessory nerve consists of two distinct portions, the medullary or bulbar, and the spinal.

Origin.—The *medullary* portion has its origin in nerve-cells in the lower part of the nucleus ambiguus, located beneath the floor of the fourth ventricle. From this origin the nerve-fibers pass forward and emerge from the medulla oblongata on its lateral aspect.

The *spinal* portion has its origin in the nerve-cells located in the lateral gray matter of the spinal cord as far down as the fifth cervical nerve. From this origin the nerve-fibers pass to the surface of the cord to emerge between the ventral and dorsal roots in from six to eight filaments, after which they unite to form a well-defined nerve. It then passes into the cranial cavity through the foramen magnum and unites with the medullary portion.

Distribution.—After the union the common trunk emerges from the cranial cavity through the jugular foramen and after sending branches to the pneumogastric and receiving other in turn from the pneumogastric as well as from the upper cervical nerves it divides into two branches—viz.:

1. An *internal* or *anastomotic* branch which soon enters the trunk of the pneumogastric nerve. The fibers of this branch are ultimately distributed to some of the pharyngeal muscles; to all of the muscles of the larynx by way of the laryngeal branches of the vagus nerve, and, according to most authorities, to the heart.

2. An *external* branch consisting chiefly of the accessory fibers from the spinal cord. It is distributed to the sterno-cleido-mastoid and trapezius muscles.

Properties.—At its origin it is a purely *motor* nerve, but in its course it exhibits some sensibility, due to the presence of anastomosing fibers.

Destruction of the *medullary* root—*e.g.*, tearing from its attachment by means of forceps, impairs the action of the muscles of deglutition and destroys the power of producing vocal sounds from paralysis of the laryngeal muscles, without, however, interfering with the respiratory movements of the larynx, these being controlled by other motor nerves. The normal rate of movement of the heart is increased by destruction of the medullary root.

Irritation of the external branch throws the trapezius and sternomastoid muscles into convulsive movements, though *section* of the nerve does not produce complete paralysis, as they are also supplied with motor influence from the cervical nerves. The sternomastoid and trapezius muscles perform movements antagonistic to those of respiration, fixing the head, neck, and upper part of the thorax, and delaying the expiratory movement during the acts of pushing, pulling, straining, etc., and in the production of a prolonged vocal sound, as in singing. When the *external* branch alone is divided, in animals, they experience shortness in breath during exercise, from a want of coördination of the muscles of the limbs and respiration; and while they can make a vocal sound, it cannot be prolonged.

Function.—Governs phonation by its influence upon the muscle regulating the position and tension of the vocal bands; influences the movements of deglutition, inhibits the action of the heart, and controls certain respiratory movements associated with sustained or prolonged muscular efforts and phonation.

Twelfth Nerve—Hypoglossal

Origin.—From nerve-cells situated deep in the substance of the medulla oblongata, on a level with the lowest portion of the floor of the fourth ventricle. From this origin the fibers pass forward and emerge from the medulla in the groove between the anterior pyramid and the olivary body.

Distribution.—The trunk formed by the union of the different filaments passes out of the cranial cavity through the anterior condyloid foramen. After emerging from the cranium, it sends filaments to the sympathetic and pneumogastric; it anastomoses with the lingual branch of the fifth pair, and receives and sends filaments to the upper cervical nerves. The nerve is finally distributed to the sternohyoid, sternothyroid, omohyoid, thyrohyoid, styloglossi, hyoglossi, geniohyoid, geniohyoglossi, and the intrinsic muscles of the tongue.

Properties.—A purely *motor* nerve at its origin, but derives sensibility outside the cranial cavity from anastomosis with the cervical pneumogastric, and fifth nerves.

Irritation of the nerve gives rise to convulsive movements of the tongue and slight evidences of sensibility.

Division of the nerve on both sides abolishes all movements of the tongue and interferes considerably with the act of deglutition.

When the hypoglossal nerve is involved in hemiplegia, the tip of the tongue is directed to the paralyzed side when the tongue is protruded, owing to the unopposed action of the geniohyoglossus on the sound side.

Articulation is considerably impaired in paralysis of this nerve, great difficulty being experienced in the pronunciation of the consonantal sounds.

Mastication is performed with difficulty, from inability to retain the food between the teeth until it is completely triturated.

Function.—Governs all the movements of the tongue and influences the functions of mastication, deglutition and articulation.

THE SENSE OF TOUCH

Touch may be defined as the sense by which pressure or traction on the skin and mucous membrane is perceived.

The physiologic mechanism involved in the sense of touch includes the skin and the mucous membrane lining the mouth, the afferent nerves, their cortical connections, and nerve-cells in the cortex of the parietal lobe.

Peripheral excitation of this mechanism develops nerve impulses which, transmitted to the cortex, evoke sensations of touch and temperature. To the skin, therefore, is ascribed a touch sense and a temperature sense. Of the touch sensations two kinds may be distinguished: viz., pressure sensations and place sensations. With the contact of an external body there arises the perception not only of the pressure, but also the perception of the place or locality of the contact. In accordance with this, it is customary to attribute to the skin a pressure sense and a location sense.

The specific physiologic stimuli to the terminal organs in the skin and oral mucous membrane are mechanic pressure and thermic vibrations.

The structure of the skin and the modes of termination of the sensory nerves have already been considered (see page 149).

The touch sense is coextensive with the skin and the mucous membrane of the mouth. The touch areas, however, are not continuous but discrete and vary in number in each square centimeter of skin. Thus in the skin of the calf 15 touch spots or areas have been counted; in the palm of the hand 40 to 50. Stimulation with a fine bristle of such an area calls forth the sensation of touch. In the tip of the index finger the touch sense is quite acute and associated with the presence of touch corpuscles of which there are about 20 to each square millimeter of surface.

The *pressure* sense varies with the sensitivity of the skin, which varies in different parts of the body in accordance with the size of the area pressed.

The *place* or *location* sense is the localization of a sensation to the place stimulated. This holds true not only for two or more points near or widely separated on the same side, but also for corresponding points on opposite sides of the body, even when the stimuli have the same intensity and are simultaneously applied.

The delicacy of the localizing power in any part of the skin is determined by testing the power which the part possesses of distinguishing the sensations produced by the contact of the points of a pair of compasses placed close together. The distance to which the points must be separated in order to evoke two separate recognizable sensations is a measure of the diameter of the sensor circle. Within this circle the two sensations become fused into one sensation. The discriminative sensibility of different regions as determined by compass points is shown in the following table; the numbers represent the distances at which two sensations are recognized:

	mm.
Tip of tongue	1.1
Palmar surface of third phalanx of index-finger	2.2
Red surface of lips	4.5
Palmar surface of first phalanx of finger	5.5
Tip of nose	6.8
Palm of hand	8.9
Lower part of forehead	22.6
Dorsum of hand	31.6
Dorsum of foot	40.6
Middle of the back	67.7

The *temperature* sense is the recognition of changes in the temperature of the skin produced in a variety of ways through the sensations of heat and cold. This sense depends on the fact that all over the skin there are small areas some of which respond to warm, others to cold objects and are therefore called hot and cold spots. When stimulated they call forth sensations of heat and cold.

THE SENSE OF TASTE

The sense of taste may be defined as the sense by which the specific quality or flavor of a substance, applied to the taste organ, is perceived. This sense is located mainly in the mucous membrane covering the surface of the tongue.

The physiologic mechanism involved in the sense of taste includes the tongue, the gustatory nerves (contained in the trunks of the chorda tympani and glosso-pharyngeal nerves) their cortical connections and nerve-cells in the gray matter of the sub-collateral convolution. The peripheral excitation of this apparatus gives rise to nerve impulses which transmitted to the brain evoke the sensations of taste. The specific physiologic stimulus is matter, organic and inorganic, in a state of solution.

Taste Buds or Beakers.—The peripheral ends of the taste nerves are provided with small ovoid bodies termed taste buds or beakers. The wall of the bud is composed of elongated curved epithelium at one point of which there is a small opening or *pore.* The interior contains narrow spindle-shaped neuro-epithelial cells provided at their outer extremity with stiff hair-like filaments which project into the taste pore. These neuro-epithelial cells are in histologic connection with the nerves of taste.

The Taste Area.—The taste area, though confined for the most part to the tongue, extends in different individuls to the mucous membrane of the hard palate, to the anterior surface of the soft palate, to the uvula, the anterior and posterior half arches, the tonsils, the posterior wall of the pharynx, and the epiglottis.

The Taste Sensations.—The sensations which arise in consequence of impressions made by different substances on the peripheral apparatus of this area are in so many instances combinations of taste, touch, temperature and smell that they are extremely difficult of classification. Nevertheless six primary tastes can be recognized: bitter, sweet, acid or sour, salt or saline, alkaline and metallic. Though the contact of any bitter, sweet, acid, salt, etc., substance with any part of the tongue will, if the substance be present in sufficient quantity or concentration, develop a corresponding sensation, some regions of the tongue are more sensitive and responsive than others. Thus, the posterior portion is more sensitive to bitter substances than the anterior; the reverse is true for sweet substances and perhaps for acids and salines.

The intensity of the resulting sensation in any given instance will depend on the degree of concentration of the substance, while its massiveness will depend on the area affected.

The essential conditions for the production of the sensations of taste are:

1. A state of solubility of the food.
2. A free secretion of the saliva, and
3. Active movements on the part of the tongue, exciting pressure against the roof of the mouth, gums, etc., thus aiding the solution of various articles and their entrance into the taste beakers.

THE SENSE OF SMELL

The sense of smell is the sense by which certain qualities of substances entering the nose are perceived.

The physiologic mechanism involved in the sense of smell includes the nasal fossæ, the olfactory nerves, the olfactory tracts, and nerve-cells in those areas of the cortex known as the uncinate convolution and anterior part of the gyrus fornicatus. Peripheral stimulation of this mechanism develops nerve impulses which, transmitted to the cortex, evoke the sensations of odor. The specific physiologic stimulus is matter in the gaseous or vaporous state.

For the appreciation of odorous particles the air must be drawn through the nasal fossæ with a certain degree of velocity. If the particles are widely diffused in the air, they must be drawn not only more quickly but more forcibly into contact with the olfactory hairs, as in the act of sniffing, the result of short energetic inspirations. To many substances the olfactory apparatus is extremely sensitive. Thus, it has been shown that a particle of mercaptan the actual weight of which was calculated to be $\frac{1}{460,000,000}$ of a milligram gives rise to a distinct sensation.

The Olfactory Sensation.—The sensations which arise in consequence of the excitation of the olfactory apparatus are very numerous and their classification is extremely difficult. For this reason it is customary to divide them into two groups: viz., agreeable and disagreeable, in accordance with the feelings they excite in the individual. As the olfactory sensations give rise to feelings rather than ideas, this sense plays in man a subordinate part in the acquisition of knowledge. In lower animals this sense is employed for the purpose of discovering and securing food, for detecting enemies and friends, and for sexual purposes. In land animals the entire olfactory apparatus is well developed and the sense keen; in some aquatic animals, as the dolphin, whale, and seal, the apparatus is poorly developed and the sense dull.

THE SENSE OF SIGHT

The physiologic mechanism involved in the sense of sight includes the eyeball, the optic nerve, the optic tracts, the thalamo-occipital tract or the optic radiation, and nerve-cells in the cuneus and adjacent gray matter. Peripheral stimulation of this mechanism develops nerve impulses which transmitted to the cortex evoke (1) the sensation of light and its different qualities—colors; (2) the perception of light and color under the form of pictures of external objects; and (3) in connection with the ocular muscles, the production of muscle sensations by which the size, distance, and direction of objects may be judged.

The specific physiologic stimulus to the terminal end-organ, the retina, is the impact of ether vibrations. In general, it may be said that, at least for the same color, the intensity of the objective vibration determines the intensity of the sensation.

The Eyeball.—The eyeball, or organ of vision, is situated at the fore part of the orbital cavity and is supported by a cushion of fat; it is protected from injury by the bony walls of the cavity, the lids, and the lashes, and is so situated as to permit of an extensive range of vision. The eyeball is loosely held in position by a fibrous membrane, the *capsule of Tenon*, which is attached on the one hand to the eyeball itself and on the other to the walls of the cavity. Thus suspended, the eyeball is capable of being moved in any direction by the contraction of the muscles attached to it.

Structure.—The eyeball is spheroid in shape and measures about twenty-four mm. in its anteroposterior diameter, and a little less in its transverse diameter. When viewed in profile, it is seen to consist of the segments of two spheres, of which the posterior is the larger, occupying five sixths, and the anterior the smaller, occupying one sixth, of the ball.

The eye is made up of several membranes, concentrically arranged, within which are inclosed the refracting media essential to vision.

The membranes, enumerating them from without inward, are as follows: the sclera and cornea, the choroid, iris and ciliary muscle, and the retina. The refracting media are the aqueous humor, the crystalline lens, and the vitreous humor.

The Sclera and Cornea.—The sclera is the opaque fibrous membrane covering the posterior five sixths of the ball. It is composed of connective tissue arranged in layers, which run both transversely and longitudinally; it is pierced posteriorly by the optic nerve about $\frac{1}{10}$ of an inch internal to the optic axis. The sclera, by its density gives form to the eye and protects the delicate structures within it, and serves for the attachment of the muscles by which the ball is moved.

The *cornea* is a transparent non-vascular membrane covering the anterior one sixth of the eyeball. It is nearly circular in shape and is continuous at the circumference with the sclera, from which it cannot be separated. The substance of the cornea is made up of thin layers of delicate, transparent fibrils of connective tissue, more or less united; between these layers are found a number of intercommunicating lymph-spaces, lined by endothelium, which are in connection with lymphatics. Leukocytes or lymph-corpuscles are often found in these spaces. At the junction of the cornea and sclera there is a circular groove, the *canal of Schlemm.*

The Choroid, the Iris and the Ciliary Muscle.—These three structures together constitute the second or middle coat of the eyeball.

The *choroid* is a dark brown membrane which extends forward nearly to the cornea, where it terminates in a series of folds, the *ciliary processes.* In its structure the choroid is highly vascular, consisting of both arteries and veins. Externally it is connected with the sclerotic by connective tissue; internally it is lined by a layer of hexagonal pigment cells, which, though usually classed as belonging to the choroid, is now known to belong, embryologically and physiologically, to the retina.

The choroid with its contained blood-vessels bears an important relation to the nutrition of the eye; it provides for the blood-supply and for drainage from the body of the eye, and presents a uniform and high temperature to the retina.

The *iris* is the circular variously colored membrane placed in the anterior portion of the eye just behind the cornea. It is perforated a little to the nasal side of the center by a circular opening, the *pupil.* The outer or circumferential border is connected with the cornea, ciliary muscle, and ciliary processes; the free inner edge forms the boundary of the pupil, the size of which is constantly changing. The framework of the iris is composed of connective-tissue blood-vessels, muscle-fibers and pigmented connective-tissue corpuscles. The anterior surface is covered with a layer of epithelial cells continuous with those covering the posterior surface of the cornea; the posterior surface is lined by a limiting membrane bearing pigment epithelial cells continuous with those of the choroid. The various colors which the iris assumes in different individuals depend upon the quantity and disposition of the pigment granules.

The muscle-fibers of the iris, which are of the non-striated variety, are arranged in two sets—sphincter and dilatator.

The *sphincter pupillæ* is a circular, flat band of muscle-fibers surrounding the pupil close to its posterior surface; by its contraction and relaxation the pupil is diminished or increased in size. The *dilatator pupillæ* consists of a thin layer of fibers arranged in a radiate manner; at the margin of the pupil they blend with those of the sphincter muscle, while at the outer border they arch to form a circular muscular layer.

The *ciliary muscle* is a gray, circular band, consisting of unstriped muscle-fibers about 1/10 of an inch long running from before backward. It is attached anteriorly to the inner surface of the sclera and cornea, and posteriorly to the choroid coat opposite the ciliary processes. At the anterior border of the radiating fibers and internally are found bundles of circular muscle-fibers, constituting the *annular muscle* of Müller. The ciliary muscle thus consists of two sets of fibers, a radiating and a circular, both of which are concerned in effecting a change in the convexity of the lens in the accommodation of the eye to near vision.

The *retina* forms the internal coat of the eye. In the fresh state it is a delicate, transparent membrane of a pink color, but after death soon becomes opaque; it extends forward almost to the ciliary processes, where it terminates in an indented border, the *ora serrata.* In the posterior part of the retina, at a point corresponding to the axis of vision, is a yellow spot, the *macula lutea,* which is somewhat oval in shape and tinged with yellow pigment. It presents in its center a depression, the *fovea centralis,* corresponding to a decrease in thickness of the retina; about 1/10 of an inch to the inner side of the macula is the point of entrance of the optic nerves. The *arteria centralis retinæ* pierces the optic nerve near the sclerotic, runs forward in its substance, and is distributed in the retina as far forward as the ciliary processes.

The retina is remarkably complex consisting of ten distinct layers from without inward. For physiologic purposes they may be resolved into three—viz.:

1. The layer of visual cells, the rods and cones.
2. The layer of bipolar cells.
3. The layer of ganglionic cell. Fig. 23.

The number of optic nerve-fibers in the retina is estimated to be about 800,000, and for each fiber there are about seven cones, one hundred rods, and seven pigment cells. The points of the rods and cones are directed toward the choroid, or away from the entering light, and dip into the pigment layer. They, with the pigment layer, are the intermediating elements in the change of the etheral vibrations into nerve force; out of these nerve vibrations the brain fashions the sensations of light, form, and color.

FIG. 23.—RETINAL CELLS.

s', z'. Visual cells with their peripheral terminations. s. Rods. z. Cones. b. Bipolar cells. g. Ganglion cells from which arise the axons of the optic nerve.

The Refracting Media.—The *vitreous humor*, which supports the retina, is the largest of the refracting media; it is globular in form and constitutes about four-fifths of the ball, it is hollowed out anteriorly for the reception of the crystalline lens. The outer surface of the vitreous is covered by a delicate, transparent membrane, termed the *hyaloid membrane*, which serves to maintain its globular form.

The *aqueous humor*, found in the anterior chamber of the eye, is a clear alkaline fluid, having a specific gravity of 1003–1009. It is secreted most probably by the blood-vessels of the iris and ciliary processes. It passes from the interior of the eye, through the canal of Schlemm and the meshes at the base of the iris, into the lymph vessels and thus increased ocular tension is prevented.

The *crystalline lens*, inclosed within its capsule, is a transparent biconvex body, situated just behind the iris and resting in the depression in the anterior part of the vitreous. The two convexities are not quite alike, the curvature of the posterior surface being slightly greater than that of the anterior. The lens measures about 1/3 of an inch in the transverse diameter and 1/5 of an inch in the anteroposterior diameter.

The *suspensory ligament*, by which the lens is held in position, is a firm,

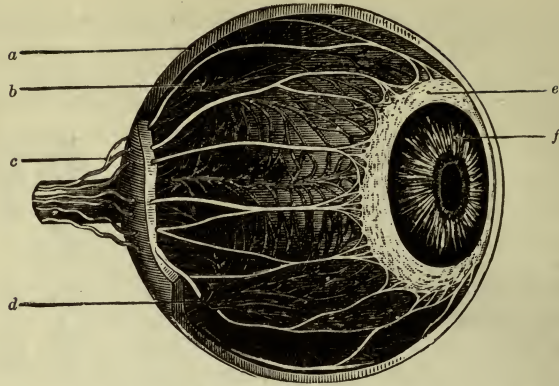

FIG. 24.—SCLEROTIC COAT REMOVED TO SHOW CHOROID CILIARY MUSCLE, AND NERVES.—(*Holden.*)

a. Sclerotic coat. *b.* Veins of the choroid. *c,* Ciliary nerves. *d.* Veins of the choroid. *e.* Ciliary muscle. *f.* Iris.

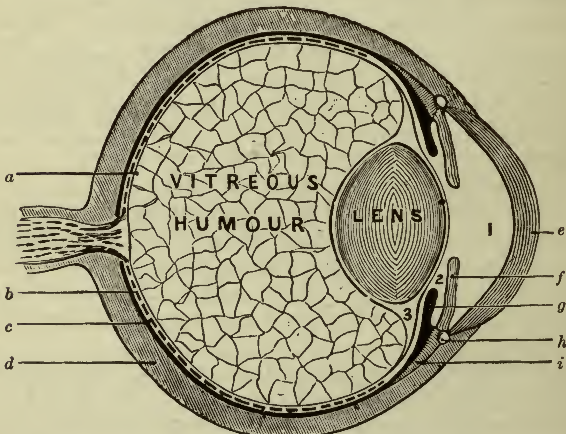

FIG. 25.—DIAGRAM OF A VERTICAL SECTION OF THE EYE.—(*Holden.*)

1. Anterior chamber filled with aqueous humor. 2. Posterior chamber. 3. Cana of Petit. *a.* Hyaloid membrane. *b.* Retina (dotted line). *c.* Choroid coat (black line). *d.* Sclerotic coat. *e.* Cornea. *f.* Iris. *g.* Ciliary processes. *h.* Canal of Schlemn or Fontana. *i.* Ciliary muscle.

transparent membrane, united to the ciliary processes. A short distance beyond its origin it splits into two layers, the anterior of which is inserted into the capsule of the lens and blends with it; the posterior, passing inward behind the lens, becomes united to its capsule. The anterior layer presents a series of foldings, *zone of Zinn*, which are inserted into the intervals of the folds of the ciliary processes. The triangular space between the two layers is the canal of Petit.

Blood-vessels and Nerves.—The structures composing the eyeball are supplied with blood by the long and short ciliary arteries, branches of the opthalmic; they pierce the sclerotic at various points and are ultimately distributed to all tissues within the ball.

The nerves distributed to the non-striated muscles of the eyeball—the ciliary muscle and the sphincter muscle of the iris—are postganglionic fibers coming from the ciliary or ophthalmic ganglion; distributed to this ganglion are preganglionic fibers coming from the central nerve system through the oculo-motor nerve. The nerves distributed to the dilatator muscle of the iris and to the blood-vessels are postganglionic fibers coming from the superior cervical ganglion; distributed to this ganglion are preganglionic fibers coming from the central nerve system through the upper thoracic nerves and the cervical cord of the sympathetic. Sensory nerves are derived from the trigeminal. The relationship of the structures composing the eyeball is shown in Figs. 24, 25.

THE PHYSIOLOGY OF VISION

The Retinal Image.—The general function of the eye is the formation of images of external objects on the free ends of the percipient elements of the retina, the rods and cones. The existence of an image on the retina can be readily seen in the excised eye of an albino rabbit, when placed between a lighted candle and the eye of an observer. Its presence in the human eye can be demonstrated with the ophthalmoscope. It is this image, composed of focal points of luminous rays, that stimulate the rods and cones, which is the basis of our sight perceptions, and out of which the mind constructs space relations of external objects. Whatever the distance, the image is generally smaller than the object; it is also reversed, the upper part of the object becoming the lower part of the image, and the right side of the object the left side of the image.

The Dioptric or Refracting Apparatus.—The formation of an image is made possible by the introduction of a complex refracting apparatus consisting of the cornea, aqueous humor, lens, and vitreous humor. Without these agencies the ether vibrations would give rise only to a sensation of diffused luminosity. Rays of light emanating from any one point arriving at the eye must traverse successively the different refracting media. In their passage from one to the other, they undergo at their surfaces changes in direction before they are finally converged to a focal point on the retina.

Inasmuch as the two surfaces of the cornea are parallel and its refractive power practically the same as the aqueous humor, the media may be reduced to three—viz.:

1. Cornea and aqueous humor.
2. The lens.
3. The vitreous humor.

The refracting surfaces may also be reduced to three—viz.:

1. Anterior surface of the cornea.
2. Anterior surface of lens.
3. Posterior surface of lens.

The refraction effected by the cornea is very great, owing to the passage of the light from the air into a comparatively dense medium, and is sufficient of itself to bring parallel rays of light to a focus about ten millimeters behind the retina. This would be the condition in an eye in which the lens was congenitally absent or after removal by surgical procedures. Perfect vision requires, however, that the convergence of the light shall be great enough to allow the image to fall upon the retina. This is accomplished in part by the crystalline lens, a body denser than the cornea and possessing a higher refractive power. After passing through the lens the rays of light if continued would come to a focus about 6.5 mm. behind the retina. On passing from the lens into the vitreous—*i.e.*, from a denser into a rarer medium—the rays are once more converged and to an extent sufficient to focalize them on the retina. The function of the cornea and lens is to focalize the rays with the production of an image.

The Visual Angle.—The visual angle is defined as the angle formed by the intersection of two lines drawn from the extremities of an object to the nodal point of the eye which lies near the posterior surface of the lens about 15.5 millimeters from the retina. Beyond the nodal point, however, the lines again diverge and form an inverted or reversed image of the object on the retina. The size of the visual angle increases with the nearness and decreases with the remoteness of the object; the retinal image correspondingly increases and decreases in size.

The Size of the Retinal Image.—The size of the retinal image depends upon the visual angle, which in turn depends upon the size of the object and its distance from the eye. At a distance of 15.2596 meters the image of an object one meter high would be one millimeter, or a thousand times smaller than the object.

The size of the image may be calculated from the following equation. The size of the object is to the size of the image, as the distance of the object from the nodal point, is to the distance of the nodal point from the retina. (The distance of the nodal point from the anterior surface of the cornea is 7.3 mm.)

Accommodation.—By accommodation is understood the power which the eye possesses of adjusting itself to vision at different distances. In a normal or emmetropic eye parallel rays of light are brought to a focus on the retina; but divergent rays—that is, rays coming from a near luminous point—will be brought to a focus behind the retina, provided the refractive media remain the same; as a result, vision would be indistinct, from the formation of diffusion circles. It is impossible to see distinctly, therefore, a near and a distant object at the same time. We must alternately direct the vision from one to the other. A normal eye does not require adjusting for parallel rays; but for divergent rays a change in the eye is necessitated; this is termed accommodation. In the accommodation for near vision the lens becomes more convex, particularly on its anterior surface. The increase in convexity augments its refractive power; the greater the degree of divergence of the rays previous to entering the eye, the greater the increase of convexity of the lens and convergence of the rays after passing through it. By this alteration in the shape of the lens we are enabled to focus light rays coming from, and to see distinctly, near as well as distant objects.

Function of the Ciliary Muscle.—Though it is admitted that the change in the convexity of the lens is caused by the contraction of the ciliary muscle and the relaxation of the suspensory ligament, the exact manner in which it does so is not understood. When the eye is in repose, as in distant vision, the suspensory ligament is tense, and the lens possesses that degree of curvature necessary for focusing parallel rays. In the voluntary efforts to accommodate the eye for near vision, the ciliary muscle contracts, the suspensory ligament relaxes, and the lens, inherently elastic, bulges forward and once again focuses the rays upon the retina. It is, therefore, termed the muscle of accommodation, and by its alternate contraction and relaxation the lens is rendered more or less convex, according to the requirements for near and distant vision.

Range of Accommodation.—Parallel rays coming from a luminous point distant not less than 200 feet do not require adjustment; from this point up to infinity no accommodation is required for perfect vision. This is termed the *punctum remotum*, and indicates the distance to which an object may be removed and yet distinctly seen. If the object be brought nearer to the eye than 200 feet, the accommodative power must come into play; the nearer the object, the more energetic must be the contraction of the ciliary muscle and the consequent increase in the convexity of the lens. At a distance of five inches, however, the power of accommodation reaches its maximum; this is termed the *punctum proximum*, and indicates the nearest point at which an object may be seen distinctly. The distance between these two points is the range of accommodation.

The Function of the Iris.—The iris plays the part of a diaphragm, and by means of its central aperture the pupil regulates the quantity of light entering the interior of the eye; by preventing rays from passing through the margin of the lens it diminishes spheric aberration. The size of the pupil depends upon the relative degree of contraction of the circular and radiating fibers; the variations in size of the pupil from variations in the degree of contraction depend upon different intensities of light. If the light be intense, the circular fibers contract, and diminish the size of the pupil; if the light diminishes in intensity, the circular fibers relax and the pupil enlarges.

Point of Most Distinct Vision.—While all portions of the retina are sensitive to light, their sensibility varies within wide limits. At the macula lutea, and more especially in its most central depression, the fovea, where the retinal elements are reduced practically to the layer of rods and cones, the sensibility reaches its maximum. It is at this point that the image is found when vision is most distinct. The macula and fovea are always in the line of direct vision. From the macula toward the periphery of the retina there is a gradual diminution in sensibility, and a corresponding decline in the distinctness of vision. In those portions of the retina lying outside the macula, the indistinctness of vision depends not only on diminished sensibility, but also upon inaccurate focusing of the rays.

Blind Spot.—Although the optic nerve transmits the impulses excited in the retina by the ethereal vibration, the nerve-fibers themselves are insensitive to light. At the point of entrance of the optic nerve, owing to the absence of the rods and cones, the rays of light make no impression. This is the blind spot. As this spot is not in the line of vision, no dark point is ordinarily observed in the field of vision—the circular space before a fixed eye within which reflections of objects are perceptible.

The *rods* and *cones* are the most sensitive portions of the retina. A ray of light entering the eye passes entirely through the various layers of the retina, and is arrested only upon reaching the pigmentary epithelium in which the rods and cones are embedded. As to the manner in which the objective stimuli—light and color, so called—are transformed into nerve impulses, but little is known. It is probable that the ethereal vibrations are transformed into heat, which excites the rods and cones. These, acting as highly specialized end organs of the optic nerve, start the impulses on their way to the brain, where the seeing process takes place. As to the relative function of the rods and cones, it has been suggested, from the study of the facts of comparative anatomy, that the rods are impressed only by differences in the intensity of light, while the cones, in addition, are impressed by qualitative differences or color.

The Eyeball a Living Camera Obscura.—The eyeball may be compared in a general way to a camera obscura. The anatomic arrangement of its structures reveals many points of similarity. The sclerotic and choroid may be compared with the walls of the chamber; the combined refractive media, cornea, aqueous humor, lens, and vitreous humor, to the lens for focusing the rays of light; the retina, to the sensitive plate receiving the image formed at the focal point; the iris, to the diaphragm, which, by cutting off the marginal rays, prevents spheric aberration and at the same time regulates the amount of light entering the eye; the ciliary muscle, to the adjusting screw, by which distinct images are thrown upon the retina in spite of varying distances of the object from which the light rays emanate.

OPTIC DEFECTS

Presbyopia.—Presbyopia may be defined as a condition of the normal eye in which the accommodation has become so reduced by age that reading has become impossible at ordinary distances. As age advances the lens gradually loses its elasticity and hence its power to increase in convexity and thickness to the same extent as in earlier life, in response to efforts of accommodation. The refractive power is, thereby, lessened and the eye is no longer able to see distinctly at the normal reading distances, viz.: 22 to 28 cm. Rays of light emanating from a luminous point at the normal reading distances are less and less converged on the retina and hence the diffusion circles increase in size. The near point, the point from which divergent rays can be focalized, therefore advances toward the far point, or recedes from the individual. The range of accommodation is, thereby, diminished.

Myopia.—Myopia may be defined as a condition of the eye characterized by an increase in the antero-posterior diameter or by a hypernormal refracting power of the lens. The former is the usual condition. In either case parallel rays of light which enter the eye are brought to a focus in front of the retina after which they diverge and give rise to diffusion circles and indistinctness of vision. Divergent rays, however, which enter the eye are focalized as usual on the retina even in its new position. The distant point, the punctum remotum, is always at a finite distance, but approaches the eye as the myopia increases. The near point is usually much nearer the eye than 20 cm. For this reason the condition is termed *near sight*.

Hypermetropia.—Hypermetropia may be defined as a condition of the eye characterized by decrease of the normal antero-posterior diameter or by a subnormal refracting power of the lens. The former is the usual condition. In either case parallel rays of light which enter the eye are, therefore, not brought to a focus when the accommodation is suspended. Falling on the retina previous to focalization, they give rise to diffusion-circles and indistinctness of the image. As no object can be seen distinctly no matter how remote, there is no *positive* far point. The near point is abnormally distant—sometimes as far as 200 cm. For this reason the condition is termed *far sight*. A hypermetropic eye without accommodative effort can focalize only converging rays on the retina.

Astigmatism.—Astigmatism may be defined as a condition of the eye characterized by an inequality of curvature of its refracting surfaces in consequence of which not all of the rays coming from a single point are brought to the same focus. The inequality may be either in the cornea or lens, or both, though usually in the cornea.

In the normal cornea the radius of curvature in the vertical meridian is a trifle shorter, 7.6 mm., than that of the horizontal, 7.8 mm., and hence its focal distance is slightly shorter. The difference, however, in the focal distances is so slight that the error in the formation of the image is scarcely noticeable. A transverse section of a cone of light coming from the cornea is practically a circle. If, however, the vertical curvature exceeds the normal to any marked extent, the rays passing in the vertical plane will be more sharply refracted and brought to a focus much sooner than the rays passing through the horizontal plane. The result will be that the cone of light will be no longer circular, but more or less elliptic. Though the vertical plane has usually the sharper curvature, it not infrequently happens that the reverse is true. For the reason that the rays from one point do not all come to the same focus or point, the condition is termed astigmatism.

Movements of the Eyeball.—The almost spheric eyeball lies in the correspondingly shaped cavity of the orbit, like a ball placed in a socket, and is capable of being rotated to a considerable extent by the six muscles which are attached to it. These muscles are the superior and inferior recti, the external and internal recti, and the superior and inferior obliqui. The four *recti* muscles arise from the apex of the orbit cavity, from which point they pass forward to be inserted into the sclera about 7 to 8 mm. from the corneal border. The *superior oblique* muscle having a similar origin passes forward to the upper and inner angle of the orbit cavity, at which point its tendon passes through a cartilaginous pulley, after which it is reflected backward to be inserted into the superior surface of the sclera about 16 mm. behind the corneal border. The *inferior oblique* muscle arises from the inner and inferior angle of the orbit cavity. It then passes outward, upward, and backward, to be inserted into the upper, posterior, and temporal portion of the sclera about 4 or 5 mm. from the optic nerve entrance.

The superior and inferior recti muscles, forming one pair, move the eye around a horizontal axis which intersects the median plane of the body in front of the eyes at an angle of 63 degrees; the external and internal recti muscles, forming a second pair, move the eye around a vertical axis; the superior and inferior oblique muscles forming the third pair rotate the globe around a horizontal axis which cuts the median plane of the body behind the eyes at an angle of 39 degrees. Thus it is that each muscle moves the eye as follows, the movement for practical purposes being referred to the cornea: The rectus externus draws the cornea simply to the temporal side, the rectus internus simply to the nose; the superior rectus displaces the cornea upward, slightly inward, and turns the upper part toward the nose (medial torsion); the inferior rectus move the cornea downward, slightly inward, and twists the upper part away from the nose (lateral torsion); the superior oblique displaces the cornea downward, slightly outward, and produces medial torsion; while the inferior oblique moves the cornea upward, slightly outward, and produces lateral torsion. These facts show that for certain movements of the eye at least three muscles are necessary.

THE SENSE OF HEARING

The physiologic mechanism involved in the sense of hearing includes the ear, the acoustic nerve, the acoustic tract (the lateral fillet or lemniscus), the acoustic radiation, and nerve-cells in the thorax of the temporal lobe.

Peripheral stimulation of this mechanism develops nerve impulses which, transmitted to the cerebral cortex, evoke the sensation of sound and its varying qualities—intensity, pitch, and timbre.

The specific physiologic stimulus to the terminal organ, the organ of Corti, is the impact of atmospheric pulsations of varying energy and rapidity.

The **ear**, or **organ of hearing,** is lodged within the petrous portion of the temporal bone. It may be, for convenience of description, divided into three portions—viz.:

1. The external ear.
2. The middle ear.
3. The internal ear or labyrinth.

The External Ear.—The external ear consists of the *pinna*, or *auricle*, and the *external auditory canal.* The *pinna* consists of a thin layer of cartilage, presenting a series of elevations and depressions; it is attached by fibrous tissue to the outer bony edge of the auditory canal; it is covered by a layer of integument continuous with that covering the side of the head. The general shape of the pinna is concave, and presents, a little below the center, a deep depression—the *concha.* The *external auditory canal* extends from the concha inward for a distance of about 1¼ inches. It is directed somewhat forward and upward, passing over a convexity of bone, and then dips downward to its termination; it is composed of both bone and cartilage, and is lined with a reflection of the skin covering the pinna. At the external portion of the canal the skin contains a number of tubular glands—The *ceruminous glands*—which in their conformation resemble the perspiratory glands. They secrete the cerumen, or ear-wax.

The Middle Ear.—The middle ear, or tympanum, is an irregularly shaped cavity hollowed out of the temporal bone and situated between the external ear and the labyrinth. It is narrow from side to side, but relatively long in its vertical and anteroposterior diameters; it is separated from the external auditory canal by a membrane—the *membrana tympani;* from the internal ear it is separated by an osseo-membranous partition, which forms a common wall for both cavities. The middle ear communicates posteriorly with the mastoid cells; anteriorly with the nasopharynx by means of the Eustachian tube. The interior of this cavity is lined by mucous membrane continuous with that lining the pharnyx (Fig. 26).

The Membrana Tympani.—The membrana tympani is a thin, translucent, nearly circular membrane, measuring about ⅖ of an inch in diameter, placed at the inner termination of the external auditory canal. The membrane is inclosed within a ring of bone, which in the fetal condition can be easily removed, but in the adult condition becomes consolidated with the surrounding bone. The membrana tympani consists primarily of a layer of fibrous tissue, arranged both circularly and radially, and forms the *membrana propria;* externally it is covered by a thin layer of skin continuous with that lining the auditory canal; internally it is

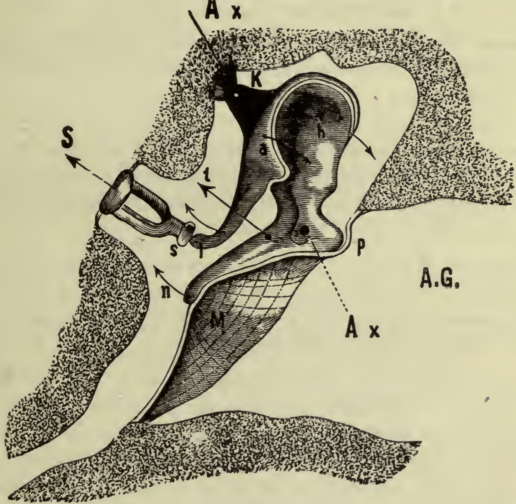

Fig. 26.—Tympanum and Auditory Ossicles (Left) Magnified.

A.G. External meatus. M. Membrana tympani, which is attached to the handle of the malleus, n, and near it the short process, p. h. Head of the malleus. a. Incus; K. its short process, with its ligament; *l.* long process. s. Sylivian ossicle. S. Stapes. Ax, Ax, is the axes of rotation of the ossicles; it is shown in perspective and must be imagined to penetrate the plane of the paper. t. Line of traction of the tensor tympani. The other arrows indicate the movement of the ossicles when the tensor contracts.

covered by a thin mucous membrane. The tympanic membrane is placed obliquely at the bottom of the auditory canal, inclining at a angle of forty-five degrees, being directed from behind and above downward and inward. On its external surface this membrane presents a funnel-shaped depression, the sides of which are somewhat convex.

The Ear Bones.—Running across the tympanic cavity and forming an irregular line of joined levers is a chain of bones which articulate with one another at their extremities. They are known as the malleus, incus, and stapes.

The forms and position of these bones are shown in figure 36.

The *malleus* consists of a head, neck, and handle, of which the latter is attached to the inner surface of the membrana tympani; the *incus*, or anvil bone, presents a concave, articular surface, which receives the head of the malleus; the *stapes*, or stirrup bone, articulates externally with the long process of the incus, and internally, by its oval base, with the edges of the foramen ovale.

The Tensor Tympani.—The tensor tympani muscle consists of a fleshy, tapering portion, ½ of an inch in length, which terminates in a slender tendon; it arises from the cartilaginous portion of the Eustachian tube and the adjacent surface of the sphenoid bone. From this origin the muscle passes nearly horizontally backward to the tympanic cavity; just opposite to the fenestra ovalis its tendon bends at a right angle over the processus cochleariformis, and then passes outward across the cavity, to be inserted into the angle of the malleus near the neck.

The Stapedius Muscle.—The stapedius muscle emerges from the cavity of a pyramid of bone projecting from the posterior wall of the tympanum; the tendon passes forward, and is inserted into the neck of the stapes bone posteriorly, near its point of articulation with the incus.

The Eustachian Tube.—The Eustachian tube, by means of which a free communication is established between the middle ear and the pharynx, is partly bone and partly cartilaginous in structure. It measures about 1½ inches in length; commencing at its opening into the nasopharynx, it passes upward and outward to the spine of the sphenoid bone, at which point it becomes somewhat contracted; the tube then dilates as it passes backward into the middle-ear cavity; it is lined by mucous membrane, which is continued into the middle ear and mastoid cells.

The Function of the Ear.—The function of the ear, as a whole, is the reception and transmission of aërial vibrations to the terminal organs concealed within the internal ear, and which are connected with the auditory nerve-fibers. The excitation of these end organs caused by the impact of the vibration arouses in the auditory nerve impulses which are then transmitted to the brain, where the hearing process takes place. In order to appreciate the functions of the individual parts of the ear, a few of the characteristics of sound waves must be kept in mind.

Sound Waves.—All sounds are caused by vibrations in the atmosphere which have been communicated to it by vibrating elastic bodies, such as membranes, strings, rods, etc. These vibrating bodies produce in the air a to-and-fro movement of its particles, resulting in a series of alternate condensations and rarefactions, which are propagated in all directions. A complete oscillation of a particle of air forward and backward constitutes a sound wave. Musical sounds are caused by a succession of regular waves, which follow one another with a certain rapidity. Noises are caused by the impact of a series of irregular waves.

All sound waves possess intensity, pitch, and equality. The *intensity*, or loudness, of a sound depends upon the amplitude of its vibrations or on the extent of its excursion. The *pitch* depends upon the number of vibrations which affect the auditory nerve in a second of time; the pitch of the note C, the first below the leger line of the musical scale, is caused by 256 vibrations a second; the pitch of the same note an octave higher is caused by 512 vibrations a second. If the vibrations are too few a second, they fail to be perceived as a continuous sound; the minimum number of vibrations capable of producing a sound has been fixed at sixteen a second; the highest pitched musical note capable of being heard has been shown to be due to 38,000 vibrations a second. In the ascent of the musical scales there is, therefore, a gradual increase in the number of vibrations and a gradual increase in the pitch of the sounds. Between the two extreme limits lies the range of audibility, which embraces eleven octaves, of which seven are employed in the musical scale.

The *quality* of sound depends upon a combination of the fundamental vibration with certain secondary vibrations of subdivisions of the vibrating body. These so-called over-tones vary in intensity and pitch, and by modifying the form of the primary wave produce that which is termed the quality of sound.

Function of the Pinna and External Auditory Canal.—In those animals possessing movable ears the pinna plays an important part in the collection of sound waves. In man, in whom the capability of moving the pinna has been lost, it is doubtful if it is at all necessary for hearing. Nevertheless an individual with dull hearing may have the perception of sound increased by placing the pinna at an angle of 45 degrees to the side of the head. The *external auditory canal* transmits the sonorous vibrations to the tympanic membrane. Owing to the obliquity of this canal it has been supposed that the waves, concentrated at the concha, undergo a series of reflections on their way to the tympanic membrane, and, owing to the position of this membrane, strike it almost perpendicularly.

Function of the Tympanic Membrane.—The function of the tympanic membrane appears to be in the reception of sound vibrations by being thrown by them into reciprocal vibrations which correspond in intensity and amplitude. That this membrane actually reproduces all vibrations within the range of audibility has been experimentally demonstrated. The membrane not being fixed, so far as its tension is concerned, does not possess a fixed fundamental note, like a stationary fixed membrane, and is, therefore, just as well adapted for the reception of one set of vibrations as for another. This is made possible by variations in its tension in accordance with the pitch of the sounds. In the absence of all sound the membrane is in a condition of relaxation; with the advent of sound waves possessing a gradual increase of pitch, as in the ascent of the music scale, the tension of the tympanic membrane is gradually increased until its maximum tension is reached at the upper limit of the range of audibility. By this change in tension certain tones become perceptible and distinct, while others become indistinct and inaudible.

Function of the Tensor Tympani Muscle.—The function of this muscle is, as its name indicates, to increase the tension of the membrane in accordance with the pitch of the sound wave. The tension of this muscle playing over the processus cochleariformis and attached at also a right angle to the handle of the malleus will, when the muscle contracts, pull the handle inward, increase the convexity of the membrane, and at the same time increase its tension; with the relaxation of this muscle, the handle of the malleus passes outward and the tension is diminished. The contractions of the tensor muscle are reflex in character and excited by nerve impulses reaching it through the small petrosal nerve and otic ganglion. The number of nerve stimuli passing to the muscle and determining the degree of contraction will depend upon the pitch of the sound wave and the subsequent excitation of the auditory nerve. The tensor tympani muscle may be regarded as an accommodative apparatus by which the tympanic membrane is so adjusted as to enable it to receive vibrations of varying degrees of pitch.

Function of the Ear Bones.—The function of the chain of bones is to transmit the sound wave across the tympanic cavity to the internal ear. The first of these bones, the malleus, being attached to the tympanic membrane, will take up the vibrations much more readily than if no membrane intervened. Owing to the character of the articulations when the handle of the malleus is drawn inward, the position of the bones is so changed that they form practically a solid rod, and are therefore much better adapted for the transmission of molecular vibrations than if the articulations remained loose. As the stapes bone is somewhat shorter than the malleus, its vibrations are slighter than those of the tympanic membrane, and by this arrangement the amplitude of the vibrations is diminished, but their force increased.

The **function of the stapedius muscle** is, according to Henle, to fix the stapes bone so as to prevent too great a movement from being communicated to it from the incus and transmitted to the perilymph. It may be looked upon, therefore, as a protective muscle.

The Function of the Eustachian Tube.—The function of the Eustachian tube is to maintain a free communication between the cavity of the middle ear and the nasopharynx. The pressure of air within and without the ear is thus equalized, and the vibrations of the tympanic membrane are permitted to attain their maximum, one of the conditions essential for the reception of sound waves. The impairment in the acuteness of hearing which is caused by an unequal pressure of the air in the middle ear can be shown—

1. By closing the mouth and nose and forcing air from the lungs through the Eustachian tube into the ear, producing an increase in pressure.
2. By closing the nose and mouth, and making efforts at deglutition which withdraws the air from the ear and diminishes its pressure.

In both instances the free vibrations of the tympanic membrane are interfered with. The pharyngeal orifice of the Eustachian tube is opened by the action of certain of the muscles of deglutition—viz., the levator palati, the tensor palati, and the palato-pharyngei muscles.

The Internal Ear.—The internal ear, or labyrinth, is located in the petrous portion of the temporal bone, and consists of an osseous and a membrane portion.

The **osseous labyrinth** is divisible into three parts—viz., the vestibule, the semicircular canals, and the cochlea.

The *Vestibule* is a small tringular-shaped cavity between the semicircular canals and the cochlea. It is separated from the cavity of the middle ear by an osseous partition which presents near its center an oval opening, the *foramen ovale.* In the living condition this opening is closed by the base of the stapes bone, which is held in position by an annular ligament. The inner wall presents a number of openings for the passage of nerve-fibers.

The Semi-circular canals are three in number, and named from their position, the superior vertical, the posterior vertical and the horizontal. These canals are at right angles one to the other and open by five orifices into the vestibule, one of the orifices, however, being common to two of the canals. Each canal near the vestibular orifice is enlarged to almost twice the size of the rest of the canal, forming what has been termed the ampulla.

The *Cochlea* forms the anterior part of the internal ear. It is a gradually tapering canal, about 1½ inches in length, which winds spirally around a central axis, the *modiolus*, two and one half times. The interior of the cochlea is partly divided into two passages by a thin plate of bone, the *lamina osseous spiralis*, which projects from the central axis two thirds of the way across the canal. These passages are termed the *scala vestibuli* and the *scala tympani*, from their communication with the vestibule and tympanum. The scala tympani communicates with the middle ear through the *foramen rotundum*, which, in the natural condition, is closed by the second membrana tympani; superiorly they are united by an opening, the helicotrema.

The whole interior of the labyrinth, the vestibule, the semicircular canals, and the scala of the cochlea, contains a clear, limpid fluid, the *perilymph*.

The **membranous labyrinth** corresponds to the osseous labyrinth with respect to form, though it is somewhat smaller in size.

The *vestibular* portion consists of two small sacs, the *utricle* and the *saccule*.

The *semicircular canals* communicate with the *utricle* in the same manner as the bony canals communicate with the vestibule. The *saccule* communicates with the membranous cochlea by the canalis reuniens. In the interior of the utricle and saccule, at the entrance of the auditory nerve, are small masses of carbonate of lime crystals, constituting the *otoliths*. Their function is unknown.

The *membranous cochlea* is a closed tube, commencing by a blind extremity at the first turn of the cochlea, and terminating at its apex by a blind extremity also. It is situated between the edge of the *osseous lamina spiralis* and the outer wall of the bony cochlea, and follows it in its turns around the modiolus.

A transverse section of the cochlea shows that it is divided into two portions by the osseous lamina and the basilar membrane:

1. The *scala vestibuli*, bounded by the periosteum and membrane of Reissner.

2. The *scala lympania*, occupying the inferior portion, and bounded above by the septum, composed of the osseous lamina and the membrana basilaris.

The *true membranous canal* is situated between the membrane of Reissner and the basilar membrane. It is triangular in shape, but is partly divided into a triangular portion and a quadrilateral portion by the *tectorial* membrane.

The Organ of Corti.—The organ of Corti is situated in the quadrilateral portion of the canal, and consists of pillars of rods of the consistence of cartilage. They are arranged in two rows—the one internal, the other external; these rods rest upon the basilar membrane; their bases are separated from one another, but their upper extremities are united, forming an arcade. In the internal row it is estimated there are about 3,500 and in the external row about 5,200 of these rods.

On the inner side of the internal row is a single layer of elongated hair-cells; on the outer surface of the external row are three such layers of hair-cells. Nothing definite is known as to their function.

The *endolymph* occupies the interior of the utricle, saccule, and membranous canals, and bathes the structures in the interior of the membranous cochlea throughout its entire extent.

The Auditory Nerve.—The auditory nerve at the bottom of the internal auditory meatus divides into—

1. A vestibular branch, which is distributed to the utricle and to the semicircular canals.

2. A cochlear branch, which passes into the central axis at its base and ascends to its apex; as it ascends, fibers are given off, which pass between the plates of the osseous lamina, to be ultimately connected with the organ of Corti.

The Function of the Semicircular Canals.—The function of the semicircular canals appears to be to assist in maintaining the equilibrium of the body; destruction of the vertical canal is followed by an oscillation of the head upward and downward; destruction of the horizontal canal is followed by oscillations from left to right. When the canals are injured on both sides, the animal loses the power of maintaining equilibrium upon making muscular movements. From these facts it is apparent that they are among the peripheral sense-organs, the physiologic action of which is the development of nerve impulses, which when transmitted to the brain assist the equilibratory mechanism to maintain the equilibrium of the body, both in the standing position and in the various modes of progression. The character of the stimulus, however, and the manner in which it acts on the specialized portion of the sense-organs (the hair-cells) is not entirely clear.

The Functions of the Cochlea.—The cochlea is the portion of the internal ear which is concerned in the perception of tones. The arrangement of the histologic elements of the organ of Corti indicates that they in some way respond to the vibrations of varying frequency and form, and through the development of nerve impulses, evoke the sensations of pitch and quality. The manner in which this is accomplished is largely a matter of speculation.

Function of the Cochlea.—It is regarded as possessing the power of appreciating the quality of pitch and the shades of different musical tones. The elements of the organ of Corti are analogous, in some respects, to a musical instrument, and are supposed, by Helmholtz, to be turned so as to vibrate in unison with the different tones conveyed to the internal ear.

Summary.—The waves of sound are gathered together by the pinna and external auditory meatus, and conveyed to the membrana tympani. This membrane, made tense or lax by the action of the tensor tympani muscle, is enabled to receive sound waves of either high or low pitch. The vibrations are conducted across the middle ear by a chain of bones to the foramen ovale, and by the column of air of the tympanum to the foramen rotundum, which is closed by the second membrana tympani, the pressure of the air in the tympanum being regulated by the Eustachian tube.

The internal ear finally receives the vibrations, which excite vibrations successively in the perilymph, the walls of the membranous labyrinth, the endolymph, and, lastly, the terminal filaments of the auditory nerve, by which they are conveyed to the brain and evoke in the cortical cells the sensations of sound.

PHONATION—ARTICULATE SPEECH

Phonation, the emission of vocal sounds, is accomplished by the vibration of two elastic membranes which cross the lumen of the larynx antero-posteriorly and which are thrown into vibration by a blast of air from the lungs.

Articulate speech is a modification of the vocal sounds or the voice produced by the teeth and the muscles of the lips and tongue and is employed for the expression of ideas.

The larynx, the organ of the voice, is situated in the fore part of the neck, occupying the space between the hyoid bone and the upper extremity of the trachea. In this situation it communicates with the cavity of the pharynx above and the cavity of the trachea below. From its anatomic relations and its internal structure—the interpolation of the elastic membranes—the larynx subserves the two widely different yet related functions, respiration and phonation.

The larynx consists primarily of cartilages, the more important of which are the *thyroid*, the *cricoid* and the *arytenoids*, united one to another in such a manner as to form a more or less rigid framework possessing in its different joints a certain amount of motion; secondarily of muscles and nerves which conjointly impart to the cartilages the degree of movement necessary to the performance of the laryngeal functions. The larynx is lined throughout by mucous membrane and covered externally by fibrous tissue.

The Vocal Bands.—The mucous membrane, as it passes downward, is reflected over the superior thyro-arytenoid ligament, and assists in the formation of the false vocal band; it then passes into and lines the ventricle, after which it is reflected outward over the superior border of the thyro-arytenoid muscle and ligament, and assists in the formation of the true vocal band; it then returns upon itself and passes downward over the lateral portion of the crico-thyroid membrane into the trachea.

The thin, free, reduplicated edge of the mucous membrane constitutes the true vocal band. The surface of the mucous membrane is covered by ciliated epithelium except in the immediate neighborhood of the vocal bands.

The *vocal bands* are attached anteriorly to the thyroid cartilage near the receding angle and posteriorly to the vocal processes of the arytenoid cartilages. They vary in length in the male from 20 to 25 mm. and in the female from 15 to 20 mm.

The Muscles of the Larnyx.—The muscles which have a direct action on the cartilages of the larnyx and determine the position of the vocal bands both for respiratory and phonatory purposes, and which regulate their tension as well, are nine in number and take their names from their points of origin and insertion: viz., two *posterior crico-arytenoids*, two *lateral crico-arytenoids*, two *thyroid-arytenois*, one *arytenoid*, and two *crico-thyroids.*

The *posterior crico-arytenoid* muscles rotate the arytenoid cartilages outward and thus separate the vocal bands and enlarge the aperture of the glottis, a condition necessary to the free entrance of the air into the lungs. Since the contraction of the crico-arytenoids has this result they are frequently spoken of as the *abductor* or the *respiratory* muscle.

The *lateral crico-arytenoid* muscles are the antagonists of the former. Their action is to rotate the arytenoid cartilages inward thus approximating the vocal bands.

The *arytenoid* muscle consists (1) of transversely arranged fibers which arise from and are inserted into the outer surface of the opposite arytenoid cartilages, and (2) of obliquely directed fibers which arise from the outer angle of one arytenoid to be inserted into the apex of the other. In their course they decussate in the median line. The action of this muscle is to approximate the arytenoid cartilages and thus obliterate that portion of the glottis between the vocal processes, the *rima respiratoria.*

The *thyro-arytenoid* muscles, acting in conjunction with the lateral crico-arytenoids, closely approximate the edges of the vocal bands so that the space between them is reduced to a mere slit—the *rima vocalis*—one of the conditions necessary for phonation.

Collectively these muscles adduct the vocal bands to the middle line and thus constrict the glottis. For this reason they are generally spoken of as the *adductors* or the *phonatory* muscles.

The *crico-thyroid* muscle at the time of its contraction draws up the anterior part of the cricoid cartilage toward the thyroid, which remains stationary, and swings the quadrate plate of the cricoid and the arytenoid cartilages downward, and backward. This movement has the result of *tensing* the vocal bands. The cricoid is at the same time drawn backward by the action of the more longitudinally disposed fibers.

Movements of the Vocal Bands.—During the intervals of speaking the vocal bands are widely separated by the tonic contraction of the posterior crico-arytenoid muscles. With each *inspiration,* however, they are separated to a somewhat greater extent; with each *expiration* they return to their former condition.

Phonation.—As soon as phonation is about to take place the vocal bands are suddenly approximated, made parallel, and increased in tension. When the foregoing conditions in the glottis are realized, the air stored or collected in the lungs is forced by the contraction of the expiratory muscles, through the narrow space between the bands. As a result of the resistance offered by this narrow outlet and the force of the expiratory muscles, the air within the lungs and trachea is subjected to pressure, and as soon as the pressure attains a certain level the vocal bands are thrown into vibrations, which in turn impart to the column of air in the upper air-passages a corresponding series of vibrations by which the laryngeal vibrations are reinforced.

The Characteristics of the Vocal Sounds.—All vocal sounds are characterized by intensity, pitch and quality.

The *intensity* or loudness of a second depends on the extent or amplitude of the to-and-fro vibration, or the extent of the excursion of the vocal band on either side of the position of equilibrium or rest; and this in turn depends on the force with which the blast of air strikes the band.

The *pitch* of the voice depends on the number of vibrations in a unit of time, a second. This will be conditioned by the length of the bands in vibration or the length and width of the aperture through which the air passes and the degree of tension to which the bands are subjected. In the emission of sounds of highest pitch the tension of the vocal bands and the narrowing of the glottis attain their maximum. In the emission of sounds of lowest pitch the reverse conditions obtain. In passing from the lowest to the highest pitched sounds in the range of the voice peculiar to any one individual, there is a progressive increase in both the tension of the vocal bands and the narrowing of the glottic aperture.

The *quality* of the voice, the timbre or tone-color, depends on the *form* combined with the intensity and pitch of the vibration. As with sounds produced by musical instruments, the primary of fundamental vibration of the vocal band is complicated by the superposition of secondary or partial vibrations (overtones). The form of the vibration will, therefore be a resultant of the blending of a number of different vibrations. The quality of the sound produced in the larynx is, however, modified by the resonance of the mouth and nasal cavities; certain of the overtones being reinforced by changes in the shape of the mouth cavity more especially, thus giving to the voice a somewhat different quality.

Speech is the expression of ideas by means of articulate sounds. These sounds may be divided into vowel and consonant sounds.

The vowel sounds, *a*, *e*, *i*, *o*, *u*, are laryngeal tones modified by the superposition and reinforcement of certain overtones developed in the mouth and pharynx by changes in their shapes. The number of vibrations underlying the production of each vowel sound is a matter of dispute.

Consonant sounds are produced by the more or less complete interruption of the vowel sounds during their passage through the organs of speech. These may be divided into:

1. Labials, *p*, *b*, *m*.
2. Labio-dentals, *f*, *v*.
3. Linguo-dentals, *s*, *z*.
4. Anterior linguo-palatals, *t*, *d*, *l*, *n*, *r*, *sh*, *zh*.
5. Posterior linguo-palatals, *k*, *g*, *h*, *y*.

The names of these different groups of consonants indicate the region of the mouth in which they are produced and the means by which the air blast is interrupted.

The Nerves of the Larynx.—The two antagonistic groups of laryngeal muscles—the respiratory and the phonatory—are innervated by two different groups of nerve-fibers both of which however are contained in the trunk of the inferior laryngeal nerve. These two groups of nerve-fibers have their origin in two separate centers in the floor of the fourth ventricle of the medulla. These centers are known as the laryngeal respiratory and the phonatory centers. The phonatory center in the medulla is in relation with a volitional or motor center in the lower portion of the precentral convolution near the anterior border. Stimulation of this area is invariably followed by bilateral adduction of the vocal bands and closure of the glottis.

REPRODUCTION

Reproduction is the function by which the species is preserved; it is accomplished by the organs of generation in the two sexes. Embryology is the science which investigates the successive stages in the development of the embryo.

GENERATIVE ORGANS OF THE FEMALE

The **generative organs of the female** consist of the ovaries, Fallopian tubes, uterus, and vagina.

The **ovaries** are two small, flattened bodies, measuring about 40 mm. in length and 20 mm. in width; they are situated in the cavity of the pelvis, and are imbedded in the posterior layer of the broad ligament; attached to the uterus by a round ligament, and to the extremities of the Fallopian tubes by the fimbriæ. The ovary consists of an external membrane of fibrous tissue, the *cortical* portion, in which are embedded the *Graafian vesicles*, and an internal portion, the *stroma*, containing blood-vessels.

The **Graafian vesicles** are exceedingly numerous, but are situated only in the cortical portion. It is estimated that each ovary contains from 20,000 to 40,000 follicles. Although the ovary contains the vesicles from the period of birth, it is only at puberty that they attain their full development. From this time onward to the catamenial period there is a constant growth and maturation of the Graafian vesicles. They consist of an external investment, composed of fibrous tissues and blood-vessels, in the interior of which is a layer of cells forming the *membrana granulosa*; at its lower portion there is an accumulation of cells, the *proligerous disc;* in which the *ovum* is contained. The cavity of the vesicle contains a slightly yellowish alkaline, albuminous fluid.

The **ovum** is a globular body, measuring about 0.3 mm. in diameter. It consists of a mass of protoplasmic material *cytoplasm*, a *nucleus* or *germinal vesicle* and a *nucleolus* or *germinal spot*. The peripheral portion of the cytoplasm is surrounded by a clear thick membrane, the *zona pellucida*, external to which is a layer of radially placed columnar epithelium forming the corona radiata. The nucleus consists of a nuclear membrane enclosing material, some of which arranged in the form of thread stains readily and hence known as *chromatin*, in the meshes of which lies a material that stains faintly and hence known as *achromatin*.

The **Fallopian tubes** are about 12 centimeters in length, and extend outward from the upper angles of the uterus, between the folds of the broad ligaments, and terminate in a fringed extremity which is attached by one of the fringes to the ovary. They consist of three coats:

1. The external, or peritoneal.
2. Middle, or muscular, the fibers of which are arranged in a circular and longitudinal direction.
3. Internal, or mucous, usually folded longitudinally, is covered with ciliated epithelial cells, which are always waving from the ovary toward the uterus.

The **uterus** is pyriform in shape, and may be divided into a body and neck; it measures about 7 cm. in length and 5 cm. in breadth in the unimpregnated state. At the lower extremity of the neck is the os externum; at the junction of the neck with the body is a constriction, the os internum. The cavity of the uterus is triangular in shape, the walls of the triangle being almost in contact.

The walls of the uterus are made up of many layers of non-striated muscle-fibers, covered externally by peritoneum, and lined internally by mucous membrane, containing numerous tubular glands, and covered by ciliated epithelial cells.

The **vagina** is a membranous canal, from 12 to 18 cm. in length, situated between the rectum and bladder. It extends obliquely upward from the surface, almost to the brim of the pelvis, and embraces at its upper extremity the neck of the uterus.

Discharge of the Ovum.—As the Graafian vesicle matures it increases in size, from an augmentation of its liquid contents, and approaches the surface of the ovary, where it forms a projection, measuring from six to twelve cm. The maturation of the vesicle occurs periodically, about every twenty-eight days, and is attended by the phenonena of menstruation. During this period of active congestion of the reproductive organs the Graafian vesicle ruptures, the ovum and liquid contents escape, and are caught by the fimbriated extremity of the Fallopian tube, which has adapted itself to the posterior surface of the ovary. The passage of the ovum through the Fallopian tube into the uterus occupies from ten to fourteen days, and is accomplished by muscular contraction and by the action of the ciliated epithelium.

Menstruation is a periodic discharge of blood from the mucous membrane of the uterus, due to a fatty degeneration of the small blood-vessels. Under the pressure of an increased amount of blood in the reproductive organs, attending the process of ovulation, the blood-vessels rupture, and a hemorrhage takes place into the uterine cavity; thence it passes into the vagina. Menstruation lasts from five to six days, and the amount of blood discharged averages from 180 to 200 c.c.

Corpus Luteum.—For some time previous to the rupture of a Graafian vesicle it increases in size and becomes vascular; its walls become thickened from the deposition of a reddish-yellow, glutinous substance, a product of cell growth from the proper coat of the follicle and the membrana granulosa. After the ovum escapes there is usually a small effusion of blood into the cavity of the follicle, which soon coagulates, loses its coloring-matter, and acquires the characteristics of fibrin, but it takes no part in the formation of the corpus luteum. The walls of the follicle become convoluted and vascular and undergo hypertrophy, until they occupy the whole of the follicular cavity. At its period of fullest development the corpus luteum measures 20 mm. and 12 mm. in depth. In a few weeks the mass loses its red color and becomes yellow, constituting the *corpus luteum*, or *yellow body*. It then begins to retract and becomes pale; and at the end of two months nothing remains but a small cicatrix upon the surface of the ovary. Such are the changes in the follicle if the ovum has not been impregnated.

The corpus luteum, after impregnation has taken place, undergoes a much slower development, becomes larger, and continues during the entire period of gestation. The difference between the corpus luteum of the unimpregnated and pregnant condition is expressed in the following table by Dalton:

	Corpus Luteum of Menstruation.	Corpus Luteum of Pregnancy
At the end of three weeks.	20 mm. in diameter; central clot reddish; convoluted wall pale.	
One month	Smaller; convoluted wall bright yellow; clot still reddish.	Larger; convoluted wall bright yellow; clot still reddish.
Two months.......	Reduced to the condition of an insignificant cicatrix.	20 mm. in diameter; convoluted wall bright yellow; clot perfectly decolorized.
Four months.......	Absent or unnoticeable.	20 mm. in diameter; clot pale and fibrinous; convoluted wall dull yellow.
Six months	Absent............	Still as large as at the end of second month; clot fibrinous; convoluted wall paler.
Nine months.......	Absent............	12 mm. in diameter; central clot converted into a radiating cicatrix; external wall tolerably thick and convoluted, but without any bright yellow color.

GENERATIVE ORGANS OF THE MALE

The **generative organs of the male** consists of the testicles, vasa deferentia, vesiculæ seminales, and penis.

The **testicles,** the essential organs of reproduction in the male, are two oblong glands, about 40 mm. in length, compressed from side to side and situated in the cavity of the scrotum.

The proper coat of the testicles, the *tunica albuginea,* is a white, fibrous structure, about one mm. in thickness; after enveloping the testicle, it is reflected into its interior at the posterior border, and forms a vertical process, the *mediastinum testis,* from which septa are given off, dividing the testicle into lobules.

The substance of the testicle is made up of the *seminiferous tubules.* which exist to the number of 840; they are exceedingly convoluted, and when unravelled are about 30 cm. in length. As they pass toward the apices of the lobules, they become less convoluted, and terminate in from twenty to thirty straight ducts, the *vasca recta,* which pass upward through the *mediastinum* and constitute the *rete testis.* At the upper part of the mediastinum the lobules unite to form from nine to thirty small ducts, the *vasa efferentia,* which become convoluted and from the *globus major* of the *epididymis;* the continuation of the tubes downward behind the testicle and a second convolution constitutes the *body* and *globus minor.*

The seminal tubule consists of a basement membrane lined by granular nucleated epithelium.

The **vas deferens,** the excretory duct of the testicle, is about 60 cm. in length, and may be traced upward from the epididymis to the under surface of the base of the bladder, where it unites with the duct of the vesicula seminalis to form the ejaculatory duct.

The **vesiculæ seminales** are two lobulated, pyriform bodies about 50 mm. in length, situated on the inner surface of the bladder.

They have an external fibrous coat, a middle muscular coat, and an internal mucous coat, covered by epithelium, which secretes a mucous fluid. The vesiculæ seminales serve as reservoirs, in which the seminal fluid is temporarily stored up.

The **ejaculatory duct,** about 20 mm. in length, opens into the urethra, and is formed by the union of the vasa deferentia and the ducts of the vesiculæ seminales.

The **prostate gland** surrounds the posterior extremity of the urethra, and opens into it by from twenty to thirty openings, the orifices of the *prostatic tubules.* The gland secretes a fluid which forms part of the semen and assists in maintaining the vitality of the spermatozoa.

The **semen** is a complex fluid, made up of the secretions from the testicles, the vesiculæ seminales, the prostatic and urethral glands. It is grayish-white in color, mucilaginous in consistence, of a characteristic odor, and somewhat heavier than water. From one to five c.c. is ejaculated at each orgasm.

The **spermatozoa** are peculiar anatomic elements, developed within the seminal tubules, and possess the power of spontaneous movement. The spermatozoa consist of a conoid head and a long, filamentous tail, which is in continuous and active motion; so long as they remain in the vas deferens they are quiescent, but when free to move in the fluid of the vesiculæ seminales, they become very active.

Origin.—The spermatozoa appear at the age of puberty, and are then constantly formed until an advanced age. They are developed from the nuclei of large, round cells contained in the anterior of the seminal tubules, as many as fifteen to twenty developing in a single cell.

When the spermatozoa are introduced into the vagina, they pass readily into the uterus and through the Fallopian tubes toward the ovaries, where they remain and retain their vitality for a period of from eight to ten days.

Fecundation is the union of the spermatozoa with the ovum during its passage toward the uterus and usually takes place in the Fallopian tube just outside the uterus. After floating around the ovum in an active manner, a single spermatozoan penetrates the ovum, this accomplished. the head and body meet and unite with the nucleus of the ovum. A series of histologic changes now arise which eventuate in the production of a new cell, the parent cell, from which the new being developes through successive division, multiplication and differentiation of cells.

The Fixation of the Ovum.—The ovum after fertilization in the oviduct, continues to divide and pass slowly to the uterus (8–10 days) where it is retained until the end of gestation. A menstrual mucosa having developed, the ovum lodges on a smooth thick area and gradually sinks beneath the surface. During the passage down the oviduct the zona pellucida has become attenuated and has been finally replaced by a thick layer of ameboid and phagocytic cells called the *trophoderm.* Upon lodgement of the ovum these cells destroy the underlying mucosa and produce a cavity into which the ovum sinks. As the ovum increases in size the mucosa gradually covers it; that portion of the mucosa toward the uterine cavity is called the *decidua capsularis* or *reflexa*, that beneath the ovum the *decidua basilaris* or *placentalis*, while the remainder constitutes the *decidua parietalis* or *vera*. As development proceeds the decidua basilaris becomes greater and ultimately develops into the placenta, the organ of nutrition and respiration.

Segmentation of the Ovum.—Immediately after fertilization the ovum divides and redivides within the diminishing zone pellucida, forming an irregular mass of cells called the *morula*. The peripheral cells form a layer, the *trophoderm*, beneath the attenuated zona pellucida, ultimately replacing that structure. The remaining cells of the morula differentiate into three masses, *ectodermal*, *entodermal* and *mesodermal*. The central cells of these masses liquefy and disappear forming thus the *ectodermal* or *amniotic* cavity, limited by the ectoderm; the *entodermal* cavity limited by the entoderm; and the *mesodermal* or celomic cavity limited by the extra-embryonic mesoderm. Meanwhile cells in various parts of the thickened trophoderm have disappeared, leaving this layer in the form of delicate trophodermal villi, the future chorionic and placental villi.

The Embryonic Shield.—The floor of the amniotic cavity consisting of ectoderm and entoderm constitute the *embryonic shield* or *disk*. As the shield increases in size, a median longitudinal thickening is seen occupying the caudal half of the area. This is the *primitive streak*, a temporary structure that is soon overshadowed by changes in the area just in front of it. Here is formed a median longitudinal, grooved ridge of ectoderm that develops rapidly in length. This is the *neural* groove and *folds*. The dorsal lips of the groove approach each other in the mid-line and fuse, separating from the original ectoderm which closes over the ectodermal tube. This tube is the *neural tube* from which the nerve system is developed. In the immediate vicinity of the head end of the primitive streak is seen a darkened area, *Hensen's node*, that represents the beginning invagination of the ectoderm in the formation of the embryonic mesoderm and notochord to be considered later. That portion of the embryonic shield that gives rise to the embryo itself becomes distinctly outlined laterally and in the head and tail regions of the neural groove. Just external to this area, the *embryonic area proper*, is a transparent area, the *area pellucida*, beyond which is the *area opaca* in which the first blood-vessels appear.

Mesoderm and Notochord.—So far in the embryonic area only ectoderm and entoderm exist. Hensen's node, at the head end of the primitive streak, represents an invagination (gastrulation) of ectoderm between ectoderm and entoderm. This invagination elongates headward in the embryonic area constituting a tube of ectodermal cells, the *chordal canal*. Later the ventral wall of the canal and the adjacent entoderm disappear, so that the chordal ectoderm temporarily forms the dorsal median boundary of the entodermal cavity. By this process a communication is established between the entodermal cavity and neural groove, called the *neuro-enteric canal*. The chordal ectoderm separates from the entoderm and then forms a solid cord of cells, the *notochord;* between entoderm and neural groove the neurenteric canal, however, persisting for some time. In the meanwhile, other ectodermic cells in the region of the chordal invagination spread between ectoderm and entoderm and form the anlage of the mesoderm. These cells by rapid proliferation soon separate ectoderm and entoderm and joins the extra-embryonic mesoderm. The separation of these two structures is complete except in the regions of the *bucco-pharyngeal* and *cloacal membranes*.

On each side of the neural groove the mesoderm becomes transversely grooved in its ectodermal surface forming a number of successive block-like masses called *primitive somites* or segments; of these, there are thirty-eight for the trunk and possibly four for the head regions. Each segment consists of three parts, the *sclerotome*, the *myotome* and the *dermatome*. Lateral to the somite is a thickened mass of mesoderm, the *intermediate-cell mass*, that laterally divides into two layers; the outer accompanies the ectoderm forming the *somatopleure*, which gives rise to the body wall; the inner joins the entoderm, forming the splanchnopleure from which the gut tract, vitelline duct and yolksac are derived.

Fetal Membranes.—As the primitive streak and neural groove are forming, the extra-embryonic mesoderm that lies beneath the trophoderm invades the trophodermic villi, forming there the *chorion* with its *villi*. Gradually the mesoderm of the roof of the amniotic cavity divides into two layers, the upper constituting chorionic mesoderm, while the under one is attached to the ectoderm of the amniotic, and forms with the latter, the *Amnion*. In the chick and some mammals the amnion is derived from the somatopleure in the folding off of the body. In amniotes the amniotic cavity is at first small, but rapidly increases in size. It contains a clear fluid, the *amniotic fluid*, which amounts at term to about one quart. It serves to protect the fetus during gestation, and at parturition it dilates the os cervis and flushes the birth canal. This liquid is derived mainly from the blood as it contains albumin, sugar, fat and inorganic salts. Traces of urea indicate that some of its constituents are derived from the embryo itself.

The caudal end of the embryonic area is left connected with the chorion by a heavy band of mesoderm termed the *belly-stalk* to which the caudal part of the amnion is attached. The entoderm is invaginated into the belly-stalk for a short distance constituting the *allantois* of higher forms; the allantois grows out between the closing somatopleure folds forming the body wall and constitutes a free sac upon which vessels, *allantoic arteries* and *veins*, develop from the embryo. This sac then spreads beneath the white shell membrane forming the organ for nutrition and respiration of these forms during the last half of their incubation periods. In mammals the extra-embryonic portion of the allantois is of little importance.

The Formation of the Placenta.—The chorionic villi increase rapidly in size and number and usually surround the whole fetal sac giving it a peculiar shaggy appearance. Blood-vessels now proceed from the embryo along the belly-stalk (not the allantois in higher forms as formerly stated). There the umbilical arteries and veins pass to the chorionic villi and send branches of those of the placental area; these vascularized villi constitute the *chorion frondosum*, while the avascular villi form the *chorion leva*. The villi of the latter disappear during the second month, leaving the chorionic membrane smooth. The villi of the chorion frondosum now penetrate the uterine glands of the decidua basilaris which by this time have been denuded of epithelium and have gained connection with the blood-vessels of the mucosa; in this manner these uterine glands have become converted into blood sinuses. The chorionic villi either attach themselves to the tunica propria of the mucosa (fixed villi) or remain free, floating villi. At the edge of the placental area very few villi develop leaving a circular channel called the *marginal sinus*. This attachment of the villi becomes marked from the third month on and is considered the beginning of placentation. From this time on to full term there is merely an increase in number of villi and vessels and thus an increase in the size of the placenta.

The placenta is the most important of the fetal structures. As it develops, conditions are established which permit of a free exchange of material between mother and child. Whether by osmosis or by an act of secretion, the nutritive materials of the maternal blood pass through the intervening membrane into the fetal blood on the one hand, while waste products pass in the reverse direction into the maternal blood on the other hand. Inasmuch as oxygen is absorbed and carbon dioxid exhaled by the same structures, the placenta is to be regarded as both a digestive and a respiratory organ. So long as these exchanges are permitted to take place in a normal manner the nutrition of the embryo is secured.

The Nutrition of the Embryo.—As the ovum passes down the oviduct it imbibes nutritive materials from the mucosa. As it lodges in the uterus it is nourished at first in the same way. The first circulation developed is the vitelline, but as the amount of nutritive material is very small in mammals its activity is limited. In the oviparous forms, however, where the nutritive material is large in amount this circulation is important. The allantoic circulation is likewise of importance in the oviparous forms and constitutes their last fetal circulation. In mammals the allantoic circulation is merely a transitonal stage in the formation of the placental circulation.

Circulation of Blood in the Fetus.—The blood returning from the placenta, after having received oxygen and being freed from carbonic acid, is carried by the umbilical vein to the under surface of the liver; here a portion of it, about one-half, passes through the *ductus venosus* into the ascending vena cava, while the remainder flows through the liver and passes into the inferior vena cava by the hepatic veins. When the blood is emptied into the right auricle, it is directed by the Eustachian valve through the foramen ovale, into the left auricle, thence into the left ventricle, and so into the aorta and to all parts of the system. The venous blood returning from the head and upper extremities is emptied, by the superior vena cava, into the right auricle, from which it passes into the right ventricle, and thence into the pulmonary artery. Owing to the condition of the lung only a small portion flows through the pulmonary capillaries, the greater part passing through the *ductus arteriosus*, which opens into the aorta at a point below the origin of the carotid and subclavian arteries. The mixed blood now passes down the aorta to supply the lower extremities, but a portion of it is directed, by the hypogastric arteries, to the placenta, to be again oxygenated.

At birth, the placental circulation gives way to the circulation of the adult. As soon as the child begins to breathe, the lungs expand, blood flows freely through the pulmonary capillaries, and the ductus arteriosus begins to contract. The foramen ovale closes about the tenth day. The umbilical vein, the ductus venosus, and the hypogastric arteries become impervious in several days as far as the bladder. Their distal ends ultimately form rounded cords.

Physiologic Activities of the Embryo.—During intrauterine life the evolution of structure is accompanied by an evolution of function. The relatively simple and uniform metabolism of the undifferentiated blastodermic membranes gradually increases in complexity and variety, as the individual tissues and organs make their appearance and assume even a slight degree of functional activity. As to the periods at which different organs begin to functionate, but little is positively known.

The primitive heart, in all probability, begins to pulsate very early, as in an embryo from fifteen to eighteen days old and measuring but 2.2 mm. in length, Coste found the amnion, the allantois, the omphalo-mesenteric vessels, and the two primitive aortæ developed. In the earlier weeks, all products of metabolism are doubtless eliminated by the placenta, structures; but as metabolism increases in complexity the liver and kidney assume excretory activity. Thus, at the end of the third month the intestine contains a dark, greenish, viscid material—meconium—composed of bile pigments, bile salts, and desquamated epithelium; the amniotic fluid, as well as the fluid within the bladder, contains urea at the end of the sixth month, indicating the establishment of both hepatic and renal activity. Contractions of the skeletal muscles of the limbs begin about the fifth month, from which it may be inferred that the mechanism for muscle activity, viz., muscles, efferent nerves, and spinal centers, has become anatomically developed and associated, and capable of coördinate activity. These contractions are, in all probability, automatic or autochthonic in character due to stimuli arising with the spinal centers. The remaining organs remain more or less inactive.

After birth, with the first inspiration and introduction of food into the alimentary canal, the physiologic mechanisms which subserve general metabolism begin to functionate and in the course of a week are fully established. At this time the cardiac pulsation averages about 135 a minute; the respiratory movements vary from 30 to 35 a minute, and are diaphragmatic in type; the urine, which was at first scanty, is now abundant and proportional to the food consumed; the digestive glands are elaborating their respective enzymes, digestion proceeding as in the adult. The hepatic secretion is active and the lower bowel is emptied of its contents; the coördinate activities of the nerve-, muscle-, and gland-mechanisms are entirely reflex in character. Psychic activities are in abeyance by reason of the incomplete development of the cerebral mechanisms.

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